1985

A Probabilistic Development of Nutrient Criteria for Louisiana Rivers and Streams (Eutrophication, Dissoved Oxygen, Algae, Standards, Nitrogen).

Constantine Evan Mericas
Louisiana State University and Agricultural & Mechanical College

8610651

Mericas, Constantine Evan

A PROBABILISTIC DEVELOPMENT OF NUTRIENT CRITERIA FOR LOUISIANA RIVERS AND STREAMS

The Louisiana State University and Agricultural and Mechanical Col. PH.D. 1985

University
Microfilms
International 300 N. Zeeb Road, Ann Arbor, MI 48106

PLEASE NOTE:

In all cases this material has been filmed in the best possible way from the available copy. Problems encountered with this document have been identified here with a check mark __√__.

1. Glossy photographs or pages _____
2. Colored illustrations, paper or print _____
3. Photographs with dark background _____
4. Illustrations are poor copy _____
5. Pages with black marks, not original copy _____
6. Print shows through as there is text on both sides of page _____
7. Indistinct, broken or small print on several pages __✓__
8. Print exceeds margin requirements _____
9. Tightly bound copy with print lost in spine _____
10. Computer printout pages with indistinct print _____
11. Page(s) ________ lacking when material received, and not available from school or author.
12. Page(s) ________ seem to be missing in numbering only as text follows.
13. Two pages numbered _____. Text follows.
14. Curling and wrinkled pages _____
15. Dissertation contains pages with print at a slant, filmed as received _____
16. Other ____________________

A PROBABILISTIC DEVELOPMENT OF NUTRIENT CRITERIA FOR LOUISIANA RIVERS AND STREAMS

A Dissertation

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
in partial fulfillment of the
requirements for the degree of
Doctor of Philosophy

in

The Department of Civil Engineering

by
Constantine E. Mericas
B.S., University of New Orleans, 1973
M.E., Louisiana State University, 1982
December, 1985

ACKNOWLEDGMENTS

The preliminary phase of this research was funded by a grant through the Louisiana Department of Environmental Quality. A special note of appreciation is extended to Roger Hartzog, Bob Hannah and Dugan Sabins, of the Water Pollution Control Division who contributed technical advice and assistance. Judy Schweiters and Kristi Lessing worked tirelessly to accurately transcribe the intensive survey data from field record sheets to computer files.

I would like to express my gratitude to Dr. Ron Malone for his encouragement and guidance throughout my career as a graduate student. I cannot say I would have gotten this far in my education without the support and intellectual environment he has provided. I would also like to extend my appreciation to the other members of my graduate advisory committee, Drs. Stephen Field, Marty Tittlebaum, Joseph Suhayda, Flora Wang and James Geaghan.

Finally, my deepest appreciation goes to my wife, Elizabeth who's been able to see through the difficult times to the future we're building for ourselves.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

The objective of this investigation was the development of quantitative criteria based on the estimation of maximum levels of oxygen demand associated with specific levels of nutrients in algal dominated streams. 1582 intensive survey records were obtained from the Louisiana Department of Environmental Quality (LA DEQ). A sub-set of 225 records was defined by a minimum chlorophyll a of 10.0 ug/l and influential observation analysis to restrict the data to streams where algal processes were likely to be dominant.

Nitrogen, as measured by total Kjeldahl nitrogen (TKN) was identified as the principle nutrient of concern in the prediction of algal associated oxygen demand in the streams represented in the data sets. A linear model describes the relationship between TKN and BOD_{20} in the region below 6.0 mg/l TKN. Variability in observed data about the model line required that the model be expressed in a probabilistic format. The probabilistic model relates the risk of exceeding any BOD standard for any given TKN concentration up to 6.0 mg/l.

In order to examine the generality of the developed nutrient criteria model, an independent data set of 7227 observations from 36 states was obtained from the STORET database for comparison purposes. A similar process as for the LA DEQ data was used to define a comparison data sub-set of 199 observations where algal processes were likely to be dominant. Of the 5 states well represented in the STORET subset, Ohio and a "No State Reported" group showed no significant difference from

the LA DEQ model, while Delaware, Pennsylvania and Minnesota showed significantly different unit BOD to TKN values in the range of 4.7 to 8.4. There was insufficient data to identify sources of regional differences.

The developed nutrient criteria model represents ubiquitous processes, minimizing reliance on site specific parameter estimations, and maximizing the value of historical databases. All evidence suggests that the model is general and will not change substantially as additional verification data becomes available.

CHAPTER I

INTRODUCTION

"Management of the environment in general consists principally of protecting it from certain kinds of insults rather than keeping it in a particular condition" John Cairns, 1983

Water quality standards reflect the designated uses of state waters and the criteria necessary to protect those uses. Nutrient criteria are based on protecting waters from the deleterious effects of eutrophication. A major adverse consequence of eutrophication upon flowing waters in the State of Louisiana is oxygen depletion resulting from excessive algal respiration and decay processes.

At the present time, the criteria for nutrients in the State of Louisiana consists of the stipulation that the "naturally occurring nitrogen to phosphorus ratio" shall be maintained, without any specific regard to concentration (LADEQ, 1985). A nitrogen to phosphorus ratio of 10:1 is widely accepted as being the boundary for algal growth limitation by either nutrient (Ram and Austin, 1983; Forsberg, 1977; Forsberg and Ryding, 1980) and is used by the State as a guide. Below 10:1 nitrogen concentrations are assumed to be the principle factor limiting to growth, while above 10:1 phosphorus is suggested as the limiting nutrient. However, without some reference to maximum concentrations, any level of nutrient enrichment satisfies the criterion, as long as the proportion is 10:1. While the regulations state that "Detailed studies of the naturally occurring levels of the various macro- and micronutrients will be utilized ... to establish numerical limits," there is no established methodology for evaluating data from these proposed studies.

The objective of this investigation was the development of quantitative criteria for setting nutrient limits such that algal associated oxygen depletion may be effectively managed. A fundamental goal was the estimation of expected maximum levels of oxygen demand based upon relationships between critical nutrients and the associated oxygen demand. The identification and development of this predictive model was central to the research. The principal emphasis of this investigation was on nutrient criteria for Louisiana rivers and streams. However, some effort was directed towards the evaluation of the study findings with regard to waters outside of the state, as criteria development is a nationwide concern.

CHAPTER II

BACKGROUND INFORMATION

The purpose of this chapter is to present background information on the relationships between nutrients, algae and oxygen demand in riverine systems. A brief summary of the current approach to estimating maximum acceptable nutrient levels in conjunction with the waste load allocation process is presented.

NUTRIENT CRITERIA

The role of nutrients in the definition of water quality is a complex one. Nutrients are both indicators of pollution and a principle driving force behind eutrophication (Porcella, Peterson and Larsen, 1982). Algal biomass, and the oxygen demand that may be associated with it are manifestations of eutrophication. Nutrient oriented eutrophication control is based the concept that the growth of biomass will be controlled by the essential nutrient that is in the least supply relative to an organism's requirements. If the sources of this critical nutrient can be identified and manipulated, then eutrophication, and its impacts can be controlled to attain specific objectives.

Other states in the region have been unsuccessful in developing nutrient criteria. Texas, for instance, states in it's regulations that nutrient criteria can't be established due to the lack of scientific data on the subject. Case by case studies are to be conducted in order to set specific limits where nutrients appear to be a problem. Neither Mississippi, nor Georgia have any nutrient criteria for streams. Florida has had some research conducted in an effort to relate nutrient concentrations to desirable fish populations (Kautz, 1980), but no specific criteria have been set. A search of the literature failed to identify any specific methodology for the establishment of numerical nutrient criteria. It was concluded that there is no precedent upon which to base the establishment of nutrient criteria in the State of Louisiana.

OXYGEN DEPLETION

Critical oxygen depletion occurs when the oxygen demand exerted by the biological components in a stream exceeds the ability of oxygen sources to keep dissolved oxygen concentrations at levels suitable for maintenance of a normal biotic community. Eutrophication contributes to oxygen depletion when the demand exerted by algal respiration and decay processes exceeds the reaeration of the water by photosynthesis and physical processes.

Oxygen depletion in a stream is generally a function of two components of biological activity. These components are:

- Autochthonous: Algal respiration and decomposition of material from internal sources

- Allochthonous: Decomposition of material from external sources

While allochthonous demand can be controlled to a large extent by limiting organic waste loading to the system, the controlling factors behind algal based oxygen demand are not so readily identifiable. Under the eutrophic conditions that predominate in Louisiana waters, autochthonous oxygen demand is expected to be a significant component of the total demand in enriched natural waters. The magnitude of this demand will determine what, if any additional demand may be safely allocated to the system in the form of waste loading without precipitating excessive oxygen depletion, and subsequent catastrophic system responses. In those instances where existing autochthonous oxygen demand alone exceeds acceptable limits, some estimate of the nutrient reduction required to reduce this background demand to tolerable levels will be required to identify appropriate courses of action. It is particularly desirable for the developed criteria to be in a format which is compatible with the waste load allocation process. Since biochemical oxygen demand (BOD) is the most widely accepted measure of potential oxygen depletion, and a fundamental parameter in waste load allocation models, this study has been directed at the development of a practical relationship between autochthonous BOD and in-situ nutrient levels.

It should be noted that the prevention of oxygen depletion as a consequence of eutrophication is fundamentally aimed at the protection of aquatic life from suffocation. Tarzwell (1983) has remarked that if waters are productive of desirable aquatic life, they will be generally suitable for all other uses, with the possible exception of domestic water supply. The US Environmental Protection Agency has also related general stream quality directly to dissolved oxygen in defining acceptable water quality as that level of quality achieved when dissolved oxygen averaged over the length of the stream meets state standards (US EPA, 1985). Since oxygen depletion is the major deleterious consequence of eutrophication in the State's streams and rivers, and natural aquatic populations will generally exist in its absence, most other pertinent use classes will be protected through adequate BOD criteria.

NUTRIENTS, ALGAE AND OXYGEN DEMAND

In order to establish specific nutrient criteria, the relationship between water column nutrient(s) and the undesirable eutrophication response, specifically BOD, must be identified. Dubois (1978) presented the only study located in the literature specifically addressing the overall relationship between nutrients and oxygen depletion. This paper was a purely theoretical development of a cusp catastrophe model of river oxygen levels as a function of temperature and nutrient levels.

A good deal of lake research has been directed towards the development of predictive relationships between nutrient loading and measures of algal biomass, usually chlorophyll a (Thomann, 1977; Baker, et. al, 1981). The majority of these relationships have been empirically derived, with the mathematical form of the relationships varying among researchers and locale. It is generally accepted that phosphorus and nitrogen are the primary limiting nutrients in natural systems. While some investigations have found reasonably strong relationships between phosphorus and biomass (Gordon, Finlayson and McComb, 1981), others have found TKN to be the most effective parameter in ranking waters relative to manifested eutrophication (Taylor, et. al, 1979). Steele (1974) states that nitrogen is at least as limiting as any other component to phytoplankton growth. Smith (1982) suggests a dual nutrient effect where nitrogen modifies the response to total phosphorus. Even when nitrogen may appear to be limiting, phosphorus is generally recognized as the first choice for a control nutrient because it's sources are more readily identified and controlled (OECD, 1982). Sources of phosphorus loading include waste water discharges and urban run-off, which may be controlled through treatment, diversion, or other means. In contrast, while waste water discharges may provide a source of nitrogen loading, a significant population of nitrogen fixing blue-green algae in an aquatic system will provide an abundant, and difficult to control source of the nutrient directly from the atmosphere. Non-point source loading from agricultural run-off may also be a significant, and difficult to manage source of nitrogen in streams (Loucks, 1983).

The relationship between biomass and associated oxygen demand is also poorly represented in the literature (Bigelow, et. al, 1977; Loucks, 1983; Mauersberger, 1983). Crane (1981) described an intensive survey of an algal dominated stream near Baton Rouge, Louisiana where a very strong linear relationship was observed between chlorophyll a, widely used as an indicator of algal biomass, and carbonaceous BOD_{20} ($R^2 = 0.9$). Bigelow, et. al (1977) noted in a discussion of algal blooms in estuaries in The Netherlands that BOD can be important as a gauge in determining how large an algal bloom must become before it is objectionable. The actual unit BOD for each species will vary significantly with a number of biological and physical factors, pertaining primarily to algal cell composition, but also involving the BOD determination methodology. The fundamental difficulty lies in the fact that relationships between chemical constituents and biological components in aquatic environments are determined by complex biochemical processes that we simply do not fully understand (Mauersberger, 1983; Jorgensen,1983; Darley, 1982).

WASTE LOAD ALLOCATION

The utility of any nutrient criteria is dependent upon its integration into the waste load allocation process. The present state-of-the-art in river management provides for BOD standards established for particular point source discharges based upon the ability of the receiving water to assimilate the waste while maintaining dissolved oxygen downstream above critical levels. Complex river models are used to simulate the stream response to waste loads under the worst conditions for waste assimilation, typically periods of low flow during the warmest and most productive summer months. In theory, the resulting BOD standard will provide adequate protection for the stream under the worst conditions, while allowing for a margin of safety under average stream conditions.

CURRENT WASTE LOAD ALLOCATION APPROACH TO NUTRIENT STANDARDS

In spite of the general lack of specific information in the literature regarding the establishment of nutrient standards, the state-of-the-art in waste load allocation does provide for an estimate of nutrient/eutrophication impact on stream oxygen levels. The current approach to nutrient impact assessment and control in algal dominated streams involves a two step analysis. The first step is the projection of the effect that modified nutrient levels from waste discharges will have on algal population density, with biomass expressed solely as chlorophyll _a_. The second step involves an estimation of the effect that the modified algal population density will have on dissolved oxygen levels downstream of the discharge as a net consequence of photosynthetic oxygen production and respiration processes. A thorough discussion of the procedure is presented by Driscoll, et. al (1984). A brief summary will serve to outline the details of this process.

The projection of algal densities is based upon inorganic nutrient concentrations "just downstream" of a discharge. The magnitude and location of the maximum algal biomass that will result from the sum of available nutrients in the stream is calculated using an algal growth model involving terms for chlorophyll, inorganic nutrients, stream travel time, phosphorus or nitrogen to chlorophyll a ratios, algal growth and death rates, net algal settling velocity, and a nutrient limitation factor. These various terms must be either estimated from field samples or taken from the literature.

There are no accepted standards for what constitutes an excessive amount of chlorophyll a, although estimates of the upper limits of acceptability range from 10 ug/l in Lake Superior to 50 ug/l in the Sacramento/San Joaquin Delta (Driscoll, et. al, 1984). In order to predict the effect of chlorophyll concentrations on stream dissolved oxygen levels, some estimation of the relationship between chlorophyll a and associated photosynthetic and respiration rates is required. Typically, these two rates are estimated using stoichiometric ratios of oxygen and carbon to chlorophyll, along with growth and death rate estimates. Using these relationships in a dissolved oxygen model, estimates are projected for the net effect that a given chlorophyll concentration will have on dissolved oxygen concentrations at any point along the stream segment under study. If the resulting predicted oxygen concentrations are too low, the calculations are rerun with some level of nutrient control imposed upon the discharge. The new predicted conditions are evaluated and the process is repeated until acceptable conditions are predicted. The model inputs (ie. nutrient loads) that correspond to acceptable predicted conditions are subsequently used as the standard(s).

The principle limitation of the current approach is that it is heavily dependent upon the availability and reliability of extensive site specific data for the estimation of the various model rate and proportionality constants. The required models are structurally and mathematically complex, often beyond the limits of practicality in the decision making process (Orlob, 1983). There has been no comprehensive assessment conducted on the cumulative effects of the uncertainities involved in parameter estimates on the reliability of these complex models in real world situations. Gromiec et. al (1983) concluded that the reliability of these models is poor to fair at best. The objective of the present investigation is to develop a practical and reliable alternative for defining maximum acceptable nutrient levels for the protection of rivers and streams.

CHAPTER III

THEORETICAL DEVELOPMENT

In this chapter the biochemical processes behind oxygen demand in algal dominated streams are discussed. From the theoretical stoichiometry it is possible to get some idea of the nature and magnitudes of the relationships that will be expected to exist between in-situ nutrients and oxygen demand.

STOICHIOMETRY

For any given stream sample dominated by autochthonous components there are four component processes that can potentially contribute to measured oxygen demand: Algal respiration, oxidation of organic matter, ammonia oxidation, and nitrite oxidation.

Although there are various reported values for algal respiration rates in laboratory cultures (Jorgensen, 1983; Fogg, 1959), using historical data it would be difficult to estimate the component of total measured oxygen demand that would be attributable to algal respiration in the BOD determination. In general, respiration would be expected to be proportional to the algal biomass in the sample. Factors such as species composition, algal population condition and sampling methodology would all be expected to effect both the respiration rates and mortality of algal cells in a BOD sample. For the purposes of this argument it will be assumed that live algae in stream samples die quickly after the beginning of the BOD determination and algal respiration is a minor contribution relative to other sources. The significance of relative magnitude will become apparent with subsequent consideration of uncertainty in observed data.

Decomposition of organic matter from biomass is potentially the greatest source of oxygen demand in a stream sample. The generalized chemical composition of algal biomass may be represented as $C_{106}H_{263}O_{110}N_{16}P$ (Mauersberger, 1983). The total bacterial decomposition of algal biomass may be represented by the reaction (Mauersberger, 1983)

$$C_{106}H_{263}O_{110}N_{16}P + 138\ O_2 \Rightarrow$$
$$106\ CO_2 + 16\ NO_3^- + HPO_4^{-2} + 122\ H_2O + 18\ H^+ \qquad (1)$$

Based upon this generalized stoichiometric representation, for every atom of nitrogen in algal biomass approximately 17.25 atoms of oxygen will be required for the complete oxidation of that biomass. In terms of mass units, approximately 19.7 grams of oxygen are required for each gram of nitrogen in the complete oxidation of biomass. Using the same generalized stoichiometric representation, about 142.5 grams of oxygen are required for each gram of phosphorus in the complete oxidation of the biomass.

The first step in the above complete decomposition process involves the oxidation of biomass and resulting production of ammonia (NH_3). This component process is commonly referred to as the exertion of carbonaceous oxygen demand. Using the same generalized composition as above, this intermediate process requires approximately 13.25 atoms of oxygen for each atom of nitrogen in the oxidized biomass. In mass units, approximately 15.1 grams of oxygen are required for each gram of nitrogen in the biomass. Thus, this component step represents about 76.6% of the total oxygen requirement in the complete oxidation of nitrogenous organic material. As an estimate of ultimate BOD, the 20 day

BOD determination is usually assumed to include the total decomposition of organic material, so it would be expected that the bulk of algal biomass in such a determination would be thoroughly oxidized, and thus taken past this intermediate step.

The oxidation of ammonia to nitrate is a two step process involving the oxidation of ammonia first to nitrite (NO_2^-) by Nitrosonomas sp., and subsequent oxidation of nitrite to nitrate by Nitrobacter sp. Ammonia produced in the initial oxidation of organic matter, as well as any present from other sources, such as excreta will represent a potential for oxygen demand through this process. The two steps may be expressed as the following two oxidation reactions:

$$NH_3 + 1.5\ O_2 \Rightarrow NO_2^{-2} + H^+ + H_2O \qquad (2)$$

$$NO_2^{-2} + 0.5\ O_2 \Rightarrow NO_3^- \qquad (3)$$

In mass units, the overall sum of these two reactions requires approximately 4.57 grams of oxygen for each gram of nitrogen present as ammonia.

Based on the stoichiometry the ultimate oxygen demand represented by any stream sample may then be estimated by either

$$BOD = 142.5\ PBIOM + 4.56\ NAMMON \qquad (4)$$

or

$$BOD = 19.7\ NBIOM + 4.56\ NAMMON \qquad (5)$$

where BOD = Ultimate BOD in grams O_2
PBIOM = Grams of phosphorus as biomass
NBIOM = Grams of nitrogen as biomass
NAMMON = Grams of nitrogen as ammonia

Where the availability of one nutrient is limited relative to biomass requirements, the cell content of the other, more available nutrient often displays considerable variability. Algal cells may, or may not exhibit "luxury" uptake of the more abundant nutrient above and beyond their minimum requirements. Thus, one of the above two equations (4 & 5) is expected to be more a more reliable description of BOD depending upon which nutrient is most critical to biomass.

NITROGEN CRITICAL SYSTEMS

It will be shown in a subsequent chapter that nitrogen is the critical nutrient in describing observed oxygen demand in the stream data evaluated for this investigation. Specifically, it will be shown that total Kjeldahl nitrogen (TKN) is the parameter of interest in modeling oxygen demand. In anticipation of this finding, a brief discussion is presented in this section concerning the theoretical relationship between oxygen demand and the total amount of oxidizable nitrogenous material in the water column as represented by TKN.

The total Kjeldahl nitrogen determination is perhaps the most common nitrogen measurement. TKN measures a composite of organic nitrogen in biomass material and ammonia nitrogen, and thus presents an estimate of the total oxidizable nitrogen. If we express the fraction of TKN that is organic nitrogen as NORG, and divide through by a volume term to get concentrations, then the overall stoichiometry can be expressed as

$$BOD = 19.7\ (NORG)(TKN) + 4.56\ (1 - NORG)(TKN) \qquad (6)$$

or

$$BOD = TKN\ (4.56 + 15.1\ NORG) \qquad (7)$$

where NORG = Fraction of TKN that is organic matter

The oxygen demand predicted by the stoichiometry will be a function of both total nitrogen in the sample and the distribution of that nitrogen among the two principal components. Figure 1 illustrates several different BOD - TKN lines that would be predicted by the stoichiometry for various organic nitrogen fractions ranging from 1, where all of the nitrogen is in organic material, to 0.2 where ammonia is the predominant form. The significance of this information is that it gives some idea of the general range and magnitude of values that might be expected in observed data.

SPECIAL CONSIDERATIONS IN STREAM SYSTEMS

Although the underlying processes are the same in all streams, stream systems exhibit considerable variability in their response to nutrient conditions. The nature of streams as dynamic bodies of water introduces factors such as depth, velocity, and travel time which effect algal growth and dynamics. Additionally, turbidity from scour and loading, as well as shading effects from trees and plants growing on stream banks may limit light availability, and influence local algal population density and composition.

As a dynamic, time transient system, the relationship between nutrient levels in a stream and the oxygen demand that will result from the mix of realized algal biomass, free organic material and inorganic compounds will be modified at any given point by a variety of site specific factors and interactions. In light of these considerations, it appears from the outset that a probabilistic approach, wherein the net effects of a multitude of modifying factors are considered in terms of uncertainty, offers the best potential for defining criteria.

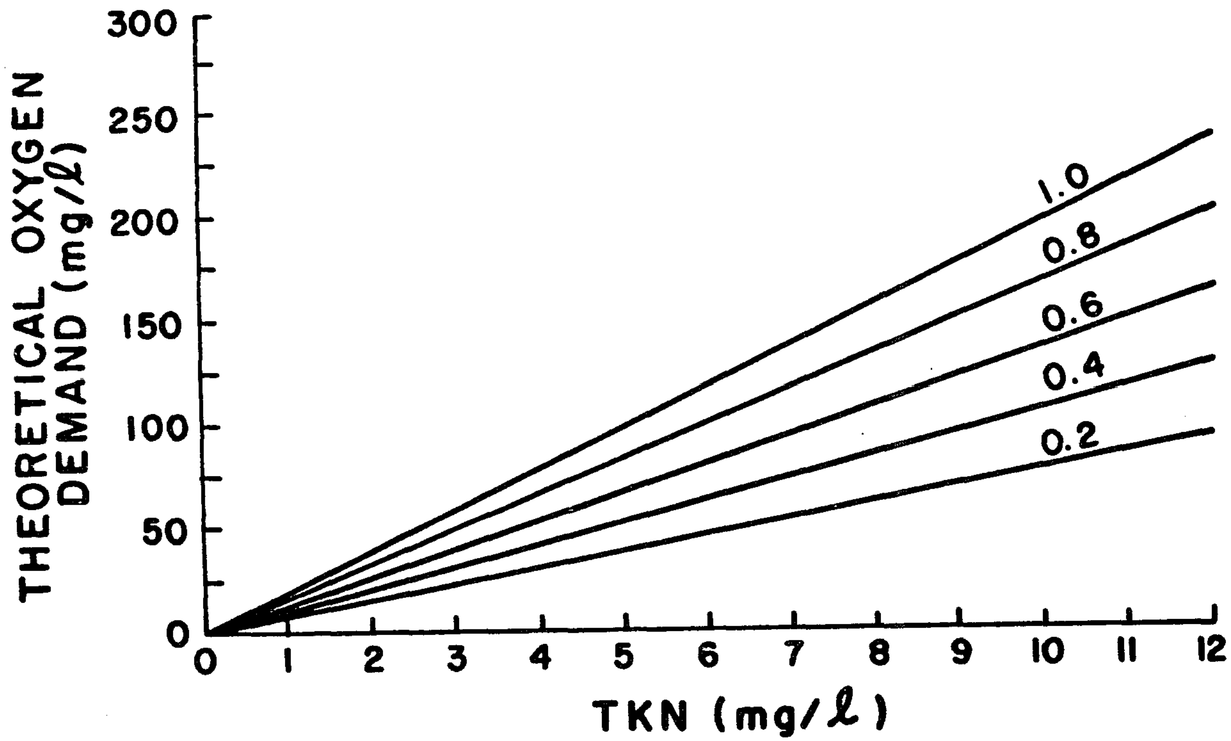

Figure 1. Several different BOD_{ult} - TKN relationship lines for a range of organic nitrogen fractions as predicted by the stoichiometry.

CHAPTER IV

STUDY DATABASE

This chapter presents a brief discussion of the data requirements for the development of a nutrient criteria model, followed by a description of the two data sets that were located and used in the research.

DATA REQUIREMENTS

THEORETICAL CONSIDERATIONS. In order to support the objective of defining a quantitative model relating in-situ nutrient concentrations to corresponding BOD levels the data base for this project must include, at a minimum, simultaneous measurements of nutrients and oxygen demand. In terms of specific water quality parameters, the data records should ideally include 20 day biochemical oxygen demand (BOD_{20}), total and ortho phosphorus, total Kjeldahl and ammonia nitrogen, and chlorophyll *a* (CHLA), corrected for pheophytin. Twenty day BOD should provide a reasonable estimate of ultimate oxygen demand. The 20 day determination allows for the death and decomposition of live algae in the sample, as well as exertion of nitrogenous oxygen demand, which is expected to be a significant component of the total autochthonous demand. Nutrient parameters must center on the various measures of phosphorus and nitrogen components of water that represent oxidizable material, principally organic matter and ammonia. There are a variety of biomass parameters available, each with distinct advantages and disadvantages. For this investigation, where large amounts of historical data are to be sought, chlorophyll *a* is most likely to be well represented in historical data records. The use of chlorophyll *a* as a biomass estimator is consistent with waste load allocation procedures.

REQUIREMENTS FOR DATA SCREENING. Some means was required for identifying those historical records where algae were a significant component of the system. Since the manifestation of algae and associated oxygen demand will be greatest during the warmer months, when physical factors, particularly temperature are minimally limiting to the development of algal populations, only data from the warmer period of the year were considered. The warmer months of the year are also of principal concern in waste load allocation, representing the worst case situation for oxygen depletion. Furthermore, some minimum level of algal density was required to insure that the data represented only those streams where algae were actually in evidence. The details of the screening process are presented in the following section.

DATA COLLECTION

LOUISIANA INTENSIVE STREAM SURVEY DATA. A review and examination of available stream water quality data for the State of Louisiana was conducted. The most appropriate and complete database examined consists of intensive survey data that the Louisiana Department of Environmental Quality (LA DEQ) has collected from selected streams throughout the State. This intensive survey data consists mainly of diurnal surveys conducted in response to suspected pollution problems. These records are unique in that they reflect repetitive sampling at short intervals, and include most of the parameters of concern to this project; specifically, total phosphorus (TP), total Kjeldahl nitrogen (TKN), BOD_{20} and chlorophyll *a*.

STORET NATIONAL DATABASE. An independent national database was sought for comparison with the findings from the Louisiana data. A search was conducted on the US EPA's STORET database for all ambient stream observations which included BOD_{20} in the record, this being the most critical parameter to the investigation. A much larger selection of parameters is available in the STORET data records than in the LA DEQ intensive survey data. A wide range of potentially pertinent parameters were collected in the STORET retrieval in addition to the previously identified parameters of principal concern.

DATABASE SUMMARY

LOUISIANA INTENSIVE SURVEY DATA. A total of 1582 sampling records were transcribed from LA DEQ field record sheets to computer files. These data constitute the majority of the stream water quality data available in the LA DEQ intensive survey files. It is believed that these data represent the most comprehensive set of stream water quality records existent in the State of Louisiana.

The intensive survey data records transcribed cover the months of late April through early October from 1980 through 1984, representing 1582 separate sampling events from 44 stream segments throughout the state. A listing of stream segments included is presented in Table 1. There was a good distribution of these segments among the water quality management basins in the State, as shown in figure 2. A list of information and parameters available and recorded for each sample is presented in Table 2. The data generally represent the three major components of water quality that are of concern to this project: nutrients, algal biomass and oxygen demand.

Table 1. Stream segments represented in the intensive survey data set, along with the distribution of total observations among the segments.

STREAM SEGMENT	NUMBER OF SAMPLES	PERCENT OF TOTAL
0203	16	1.011
0206	138	8.723
0207	84	5.310
0309	7	0.442
0402	51	3.224
0403	14	0.885
0404	48	3.034
0408	118	7.459
0409	56	3.540
0410	21	1.327
0411	36	2.276
0415	54	3.413
0418	26	1.643
0425	24	1.517
0501	34	2.149
0504	16	1.011
0505	64	4.046
0515	38	2.402
0517	108	6.827
0519	16	1.011
0525	8	0.506
0527	12	0.759
0533	38	2.402
0607	28	1.770
0608	16	1.011
0801	101	6.384
0811	8	0.506
0815	14	0.885
0827	14	0.885
0909	27	1.707
1003	12	0.759
1004	10	0.632
1005	82	5.183
1009	12	0.759
1011	28	1.770
1016	18	1.138
1023	30	1.896
1109	25	1.580
1201	14	0.885
1205	72	4.551
1211	44	2.781

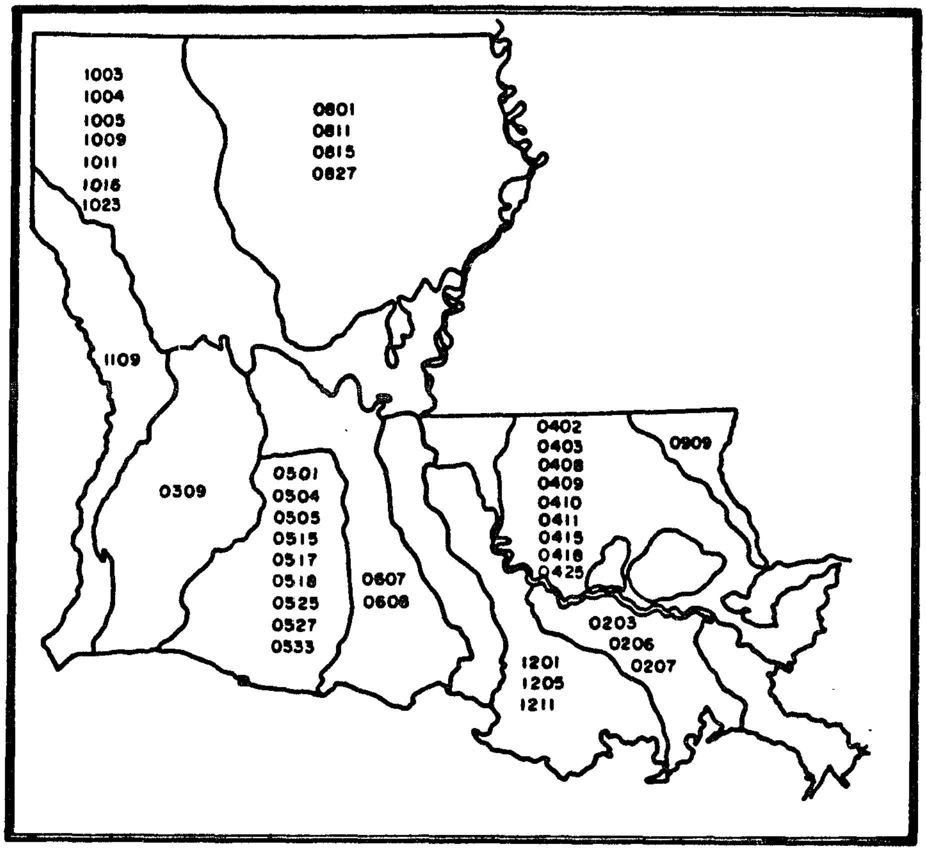

Figure 2. Distribution of stream segments in the LA DEQ data set among the water quality management basins of Louisiana.

Table 2. Information and parameters recorded for each station in the intensive survey data set.

General information:
Segment number
Sample designation
Day or night sample
Date collected
Water quality parameters:
Depth of stream (m)
Dissolved oxygen [DO] (mg/l)
Temperature (°C)
Conductivity (umhos)
20 day BOD [BOD_{20}] (mg/l)
20 day BOD - nitrogen suppressed (mg/l)
Total phosphorus [TP] (mg/l)
Total Kjeldahl nitrogen [TKN] (mg/l)
Chlorophyll *a* - uncorrected [U_CHLA] (ug/l)
Chlorophyll *a* - corrected [C_CHLA] (ug/l)
Pheophytin [PHEO_A] (ug/l)
Stream velocity (ft/sec)

Table 3 summarizes the LA DEQ intensive survey data set. Correlation coefficients were calculated for all possible parameter pairs as a preliminary step in identifying potential relationships in the data. Table 4 presents the results of this correlation analysis. Unsuppressed BOD_{20} had the highest correlation coefficients with the nutrient parameters (ie. TP and TKN). This observation is consistent with the theoretical development that was previously presented. It is significant that the two nutrient parameters were considerably more highly correlated with BOD_{20} than any of the biomass parameters (CHLA, C_CHLA and PHEO_A). This observation is not surprising since chlorophyll a, although widely used, is also widely recognized as being a variable, and somewhat unreliable indicator of algal biomass (Fogg, 1959; Darley, 1982; Kopf, 1983). Moreover, nutrients in non-algal biomass also represent a potential oxygen demand which would not be reflected by chlorophyll a. Based upon this analysis, TKN and TP offer the best potential for development of a predictive BOD_{20} model.

One of the objectives of screening the data was to insure that the data represent conditions where algal processes dominate the stream and present a significant problem to water quality. To this end, all observations where CHLA values were either missing or below 10 ug/l were discarded. A minimum chlorophyll a concentration of 10.0 ug/l was chosen based upon the use of 10.0 ug/l as a threshold for algae problems in studies in other parts of the country (Driscoll, et. al, 1984; Walker, 1984). It was assumed that the absence of chlorophyll a data indicated that State survey personnel judged that algae populations were too small to justify sampling for chlorophyll a. This filtering process resulted in an improvement in correlation with BOD_{20} for TP (r=0.46) and a

Table 3. Summary of parameters examined in the intensive survey data.

Parameter	N	Mean	Standard Deviation	Minimum	Maximum
Dissolved oxygen (mg/l)	1542	4.329	2.706	0.0	23.0
Temperature (^{o}C)	1542	27.6	3.14	15.0	38.0
Conductivity (umhos)	1484	1620.2	6421.0	0.01	177,000
BOD_{20} - N suppressed (mg/l)	1512	9.95	23.68	0.40	483.0
BOD_{20} (mg/l)	1513	16.28	29.97	0.50	555.0
TP (mg/l)	1565	0.960	1.930	0.010	34.80
TKN (mg/l)	1561	2.707	4.148	0.070	62.30
Chlorophyll a (ug/l)					
Uncorrected	177	44.64	71.97	1.20	624.0
Corrected	501	22.35	31.20	0.00	240.6
Pheophytin a (ug/l)	501	15.98	19.15	1.00	222.3

Table 4. Results of correlation analysis on the entire DEQ intensive survey data set. Given for each combination of parameters is the correlation coefficient (R), the probability of observing a larger numerical R value under the null hypothesis of no correlation, and the number of observations examined.

	DO	TEMP	COND	BOD20	BOD20S	TP	TKN
DO	1.00000	0.14465	0.07359	-0.19185	-0.14973	-0.17869	-0.22164
	0.0000	0.0001	0.0047	0.0001	0.0001	0.0001	0.0001
	1542	1533	1475	1479	1478	1532	1528
TEMP	0.14465	1.00000	0.05821	-0.07867	-0.07121	-0.00309	-0.00542
	0.0001	0.0000	0.0253	0.0025	0.0062	0.9037	0.8324
	1533	1542	1477	1479	1478	1532	1528
COND	0.07359	0.05821	1.00000	-0.02989	-0.01364	-0.04092	-0.03475
	0.0047	0.0253	0.0000	0.2600	0.6073	0.1163	0.1830
	1475	1477	1484	1422	1421	1474	1470
BOD20	-0.19185	-0.07867	-0.02989	1.00000	0.95038	0.38597	0.52243
	0.0001	0.0025	0.2600	0.0000	0.0001	0.0001	0.0001
	1479	1479	1422	1513	1511	1509	1505
BOD20S	-0.14973	-0.07121	-0.01364	0.95038	1.00000	0.30970	0.43498
	0.0001	0.0062	0.6073	0.0001	0.0000	0.0001	0.0001
	1478	1478	1421	1511	1512	1508	1504
TP	-0.17869	-0.00309	-0.04092	0.38597	0.30970	1.00000	0.75492
	0.0001	0.9037	0.1163	0.0001	0.0001	0.0000	0.0001
	1532	1532	1474	1509	1508	1565	1561
TKN	-0.22164	-0.00542	-0.03475	0.52243	0.43498	0.75492	1.00000
	0.0001	0.8324	0.1830	0.0001	0.0001	0.0001	0.0000
	1528	1528	1470	1505	1504	1561	1561
CHLA	-0.07211	0.22943	-0.00163	0.29333	0.36545	0.20262	0.43357
	0.3444	0.0023	0.9836	0.0001	0.0001	0.0070	0.0001
	174	175	162	177	176	176	176
C_CHLA	0.17807	0.22392	0.08849	0.18574	0.15669	0.19577	0.26998
	0.0001	0.0001	0.0574	0.0001	0.0004	0.0001	0.0001
	489	489	462	499	498	499	499
PHEO_A	0.18010	0.15061	-0.00614	0.19057	0.15539	0.21153	0.22877
	0.0001	0.0008	0.8954	0.0001	0.0005	0.0001	0.0001
	489	489	462	499	498	499	499

	CHLA	C_CHLA	PHEO_A
CHLA	1.00000	0.99274	0.81931
	0.0000	0.0001	0.0001
	177	116	116
C_CHLA	0.99274	1.00000	0.84581
	0.0001	0.0000	0.0001
	116	501	501
PHEO_A	0.81931	0.84581	1.00000
	0.0001	0.0001	0.0000
	116	501	501

reduction for TKN (r=0.45). This filtered data subset, consisting of 262 observations was used as the basis for further model development. Table 5 presents a summary of the filtered data subset, while Table 6 contains a list of stream segments represented in this subset. A complete data listing for this subset is presented in Appendix A.

Approximately 83 percent of the total data records in the intensive survey database examined were discarded in the screening process, falling outside of the boundary criteria for the model development. It should be noted that roughly half of the records were discarded because they were taken at night when State conducted monitoring does not typically include chlorophyll samples. Furthermore, a large number of observations were discarded because they did not contain coincident data for all of the critical parameters (ie C_CHLA, TKN, BOD_{20}). 48 percent of all the chlorophyll a data fell below the limit of 10 ug/l. This latter observation suggests that, although eutrophication is clearly a significant problem in Louisiana's rivers and streams, it did not predominate in the intensively monitored segments.

The filtering process resulted in a decrease in variability for the two main nutrient parameters in the data set. For example, the unfiltered data set TKN data (Table 3.) had a standard deviation of 4.148, corresponding to a coefficient of variation of 153%, while after discarding those observations where chlorophyll a data was either missing or below 10.0 ug/l (Table 5.) the c.v. was reduced to 122%. A similar reduction was observed in the TP data where the c.v. went from 201% to 143%. It appears that the filtering process was effective in defining a generally less variable subset of the unfiltered data.

Table 5. Summary of data subset filtered to best represent conditions where algae are able and likely to predominate. (ie. C_CHLA $\geq$ 10.0 ug/l)

	BOD20 (mg/l)	TP (mg/l)	TKN (mg/l)	C_CHLA (ug/l)
Mean	19.47	0.872	2.881	38.99
S.D.	38.84	1.249	3.513	35.58
Minimum	2.30	0.050	0.130	10.20
Maximum	519.00	7.800	29.300	240.60
N	262	262	262	263

Table 6. Distribution of the filtered LA DEQ data among stream segments in the state of Louisiana.

SEGMENT NUMBER	OBSERVATIONS	PERCENT OF TOTAL
0203	8	3.042
0207	32	12.167
0402	20	7.605
0404	15	5.703
0408	17	6.464
0409	10	3.802
0411	5	1.901
0415	11	4.183
0418	11	4.183
0501	6	2.281
0504	7	2.662
0505	22	8.365
0515	3	1.141
0517	8	3.042
0533	17	6.464
0607	4	1.521
0801	2	0.760
0815	5	1.901
1003	6	2.281
1005	18	6.844
1009	1	0.380
1011	3	1.141
1016	3	1.141
1023	5	1.901
1109	2	0.760
1211	22	8.365

was effective in defining a generally less variable subset of the unfiltered data.

STORET NATIONAL DATA. A total of 7227 observations were obtained in the STORET retrieval for the warmest months of May through September. Table 7 presents a statistical summary of the requested data. Table 8 presents a breakdown of the distribution of the data among the states, while Table 9 presents the monthly distribution of the observations. Correlation analysis, as described above for the intensive survey data showed strong correlation between BOD_{20} and total ortho-phosphate ($r=0.70$, $n=1851$). Dissolved nitrite-nitrate and total organic Kjeldahl nitrogen (TOKN) had numerically higher correlation coefficients ($r=0.78$ and 0.77 respectively) but had relatively few observations ($n=40$ and 24 respectively).

The same general filtering criteria as discussed above was used in identifying a subset of the STORET data that would be representative of algal dominated streams. However, in this case the 10 ug/l corrected chlorophyll a threshold cited in the literature for algal problems in other parts of the country was used, as opposed to the higher 15 ug/l value used with the Louisiana data. A summary of the filtered subset is presented in Table 10, while Table 11 presents the distribution of the data among the states. A complete data listing is presented in Appendix B. With this filtered subset, the best correlations with BOD_{20} were with TKN ($r=0.49$, $n=204$) and total ammonia ($r=0.51$, $n=308$).

The filtering process resulted in an even more dramatic reduction in parameter variability in the STORET data than was observed in the LA DEQ data. The full STORET data set (Table 7) had enormous c.v.'s for

BOD_{20} (813%), TKN (432%) and TP (1028%). After the data had been filtered (Table 10) these c.v's were reduced to 100%, 107%, and 151% respectively.

Table 7. Statistical summary of the storet data retrieval.

VARIABLE	N	MEAN	STANDARD DEVIATION	SKEWNESS	MAXIMUM VALUE	MINIMUM VALUE
BOD20	9330	22.250	180.860	30.122	9400.000	0.000
BOD5	8429	6.529	35.215	26.490	1680.000	0.080
C_CHLA_F	319	13.692	20.270	3.180	129.000	0.300
U_CHLA	158	24.703	33.901	2.233	206.100	0.100
C_CHLA_S	330	18.969	23.202	5.739	290.000	0.000
CHLA	141	0.675	1.342	5.236	10.600	0.000
DO	5382	7.647	5.107	39.750	310.000	0.000
DO_PROBE	1709	7.533	2.515	0.281	19.500	0.100
TN	170	0.730	0.736	7.824	8.640	0.150
ORG_N	2714	0.909	2.528	24.886	90.390	0.010
DKN	108	1.105	1.011	1.474	4.380	0.100
TKN	4766	2.487	10.740	30.589	519.000	0.010
TOKN	31	1.586	3.463	4.017	17.290	0.220
TNO2NO3	3943	1.035	2.239	11.638	55.000	0.001
DNO2NO3	44	0.390	0.755	5.548	5.000	0.010
DNH3NH4	68	0.092	0.090	2.109	0.450	0.010
TNH3NH4	7526	1.009	6.124	53.079	442.000	0.001
TP	6082	0.863	8.872	43.096	500.000	0.006
PO4	475	0.659	0.905	2.418	5.966	0.020
T_PO4	2122	0.401	1.150	4.293	9.500	0.001
D_PO4	679	0.419	1.389	8.208	17.000	0.001
TEMP	7218	19.558	6.577	-0.760	43.000	0.000

Parameter Abbreviations:

C_CHLA_F - Corrected chlorophyll *a* by fluorimetry
U_CHLA - Uncorrected chlorophyll *a*
C_CHLA_S - Corrected chlorophyll *a* by spectrophotometry
CHLA - Chlorophyll *a*
DKN - Dissolved Kjeldahl nitrogen
TOKN - Total organic Kjeldahl nitrogen
ORG_N - Organic nitrogen
TNO2NO3 - Total nitrites & nitrates
DNO2NO3 - Dissolved nitrites & nitrates
TNH3NH4 - Total ammonia
DNH3NH4 - Dissolved ammonia
PO4 - Ortho-phosphorus
T_PO4 - Total ortho-phosphorus
D_PO4 - Dissolved ortho-phosphorus
DO_PROBE - Dissolved oxygen by electronic probe

Table 8. The distribution of data in the STORET retrieval among the states.

State	Observations	Percent of Total
Alabama	31	0.34
Arkansas	33	0.36
California	4	0.04
Delaware	69	0.75
Florida	78	0.85
Georgia	2	0.02
Idaho	82	0.90
Illinois	6	0.06
Indiana	452	4.94
Iowa	31	0.34
Kansas	21	0.23
Kentucky	328	3.59
Maine	113	1.24
Massachusetts	60	0.66
Michigan	1323	14.46
Minnesota	65	0.71
Missouri	142	1.55
Nebraska	15	0.16
Nevada	121	1.32
New Jersey	489	5.35
New York	56	0.61
North Carolina	13	0.14
North Dakota	18	0.20
Ohio	2660	29.08
Oklahoma	100	1.09
Oregon	116	1.27
Pennsylvania	740	8.09
South Carolina	616	6.73
South Dakota	2	0.02
Tennessee	213	2.33
Texas	12	0.13
Vermont	82	0.90
Virginia	16	0.18
Washington	101	1.10
West Virginia	892	9.75
Wisconsin	28	0.31
No State Specified	178	1.94

Table 9. Distributionof the data in the STORET retrievalamong the months of the year.

Month	Observations	Percent of Total
Jan.	176	1.90
Feb.	170	1.84
Mar.	216	2.34
Apr.	340	3.69
May	550	5.96
Jun.	970	10.51
Jul.	1506	16.32
Aug.	2681	29.06
Sept.	1459	15.81
Oct.	725	7.86
Nov.	230	2.49
Dec.	203	2.20

Table 10. Statistical summary of the filtered STORET data. (C_CHLA>10 ug/l)

Parameter	Observations	Mean	S.D.	Min	Max.
BOD_{20} mg/l	310	9.12	9.12	0.6	116.0
BOD_5 mg/l	277	3.56	2.96	0.4	20.5
TKN mg/l	206	1.241	1.331	0.100	11.00
Ammonia mg/l	310	0.473	0.731	0.001	6.199
NO_2/NO_3 mg/l	125	1.836	3.552	0.00	17.00
TP mg/l	286	0.310	0.469	0.020	3.789
PO_4 mg/l	265	0.141	0.214	0.00	2.149
DO mg/l	25	6.88	2.71	1.30	13.70
C_CHLA_S[1] ug/l	192	25.49	17.01	10.0	101.5
C_CHLA_F[2] ug/l	118	29.86	26.07	10.0	129.0

1. Corrected chlorophyll *a* by spectrophotometry
2. Corrected Chlorophyll *a* by fluorimetry

Table 11. Distribution of the filtered STORET data among the states.
(C_CHLA $\geq$ 10.0 ug/l)

State	Observations	Percent of Total
Delaware	29	9.4
Idaho	5	1.6
Massachusetts	8	2.6
Michigan	95	30.8
Minnesota	20	6.5
Missouri	4	1.3
New Jersey	3	1.0
New York	7	2.3
Ohio	23	6.8
Pennsylvania	73	23.7
Tennessee	1	0.3
Virginia	1	0.3
No State Specified	41	13.3

CHAPTER V

CRITERIA MODEL DEVELOPMENT

This chapter details the identification of a relationship between the critical nutrient parameter and 20 day BOD in the LA DEQ data set. The general nature of the relationships between TP, TKN and BOD_{20} are described and evaluated to determine the best predictive model over the region of practical BOD_{20} standard values. The STORET data are similarly evaluated and the results compared with those from the LA DEQ data.

MODEL IDENTIFICATION

All of the model development and preliminary evaluations were conducted using the LA DEQ data only. The STORET data was used principally for comparison with, and verification of the results from the Louisiana data.

The filtered data, as defined in the previous section and summarized in Table 5, show a two phase relationship in plots of BOD_{20} against both TP and TKN (Figures 3 & 4). In both cases there appears to be a region of increasing BOD values with increasing nutrient concentrations up to a BOD level of about 35.0 mg/l, beyond which the relationships appear to flatten out. There is a theoretical basis for this observation in that as nutrients increase in concentration, algae, and by extension BOD_{20}, would be expected to be increasingly limited by other factors, such as light (Mur, 1980). Eventually there will be a point where algal biomass is independent of nutrients and physical factors become the critical controlling influence.

Before any models were fit to the data, an examination was made to

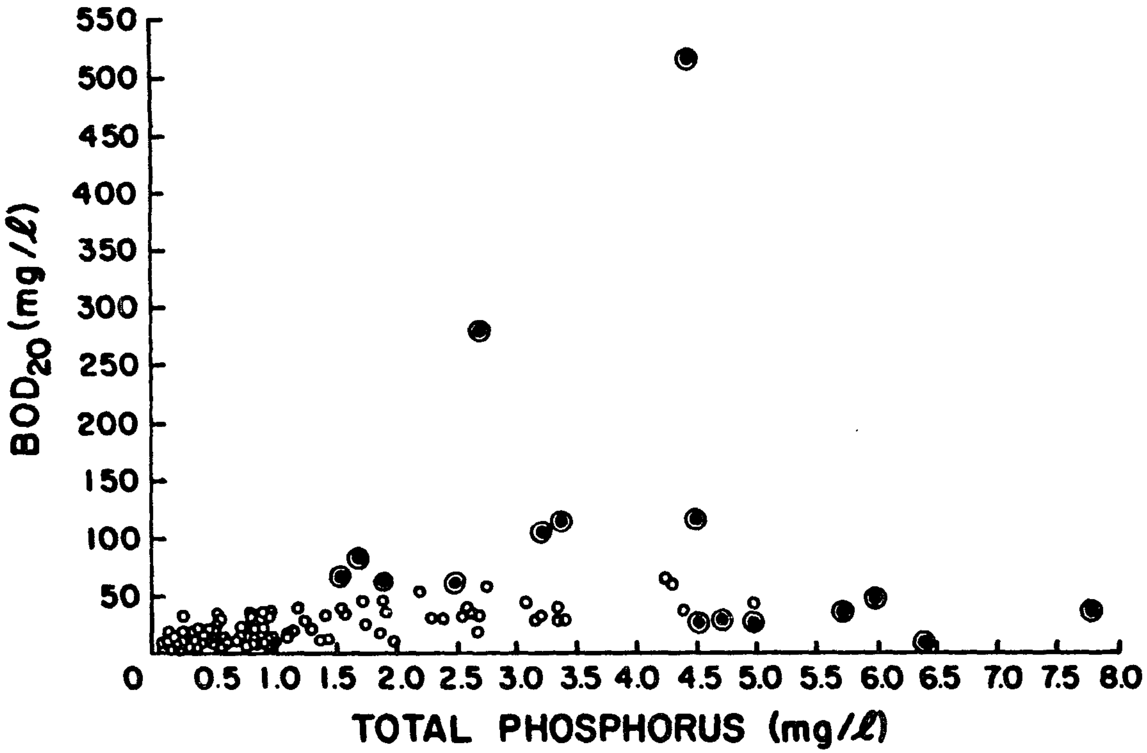

Figure 3. A plot of observed BOD_{20} versus TP in the filtered LA DEQ data set. The circled points were subsequently identified as outliers (n=262).

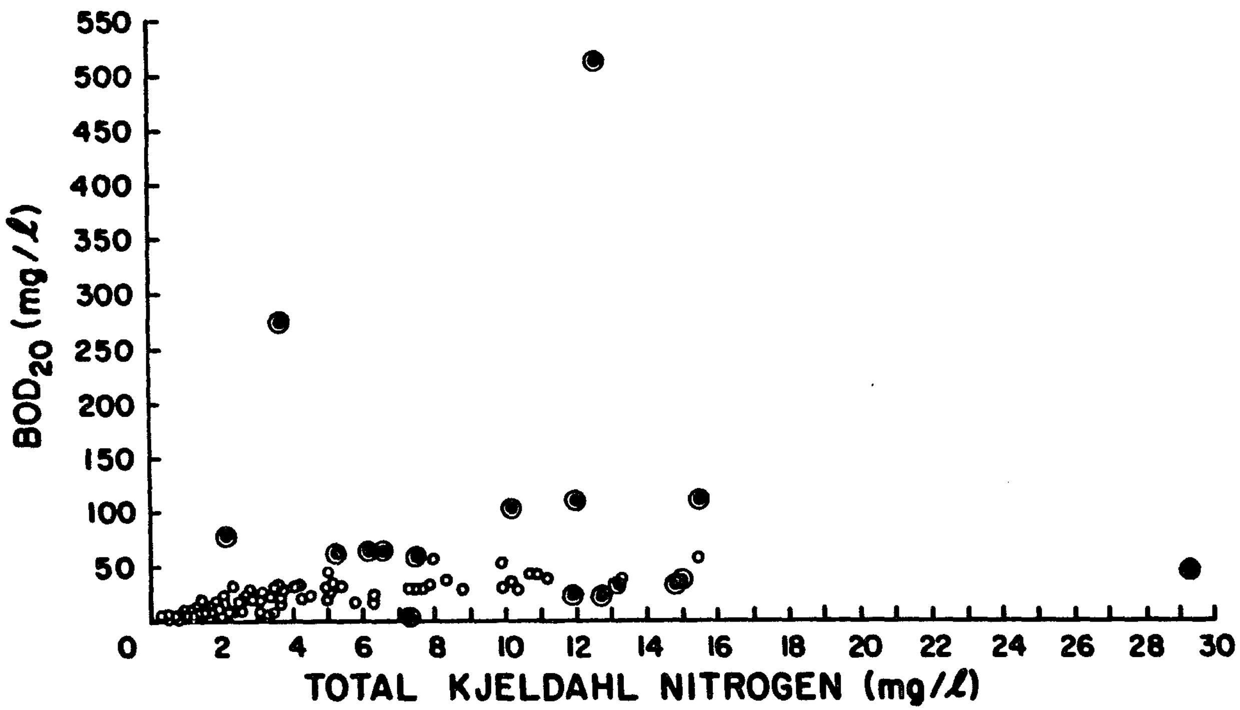

Figure 4. A plot of observed BOD_{20} versus TKN in the filtered LA DEQ data set. The circled points were subsequently identified as outliers (n=262).

identify outlier points. There are a handful of observations in Figures 3 and 4 that appear to be obvious outliers which may disproportionately influence the fitting of a model to the data. Influential observation analysis (Montgomery and Peck, 1982) identified 18 observation records which were disproportionately influential in fitting linear models to the data. Appendix C contains a listing of the SAS program used in this analysis. It was concluded that these 18 points were not representative of the same population as the balance of the data. In each case, one or more of the parameter values were extremely high relative to the rest of the data (Table 12.). These observations, identified in Figures 3 & 4 by circles, were discarded.

Piecewise regression was used to fit two phase linear models to the remaining data using either TP or TKN. This technique allows for fitting both the usual regression parameters of slope and intercept, as well as the joining point where the two functions meet. A listing of the SAS program used in fitting the model is presented in Appendix C. The analysis resulted in two functions describing the data in terms of TKN:

$$BOD_{20} = 0.79 + 6.43\ TKN \qquad \text{where } TKN \leq 6.0\ mg/l \qquad (8)$$

and

$$BOD_{20} = 9.63 + 2.99\ TKN \qquad \text{elsewhere} \qquad (9)$$

The intercept term in equation 8 was not significantly different from zero. Thus, the data is described by a zero intercept function below a TKN of 6.0 mg/l and the much flatter function represented by equation 9 above this value.

A similar piecewise regression using TP resulted in the definition of the following two functions decribing the data:

$$BOD_{20} = 4.94 + 16.15\ TP \qquad \text{where } TP \leq 1.90\ mg/l \qquad (10)$$

and

$$BOD_{20} = 20.9 + 5.18\ TP \qquad \text{elsewhere} \qquad (11)$$

Table 12. Outlier records that were discarded from consideration in the development of the nutrient criteria model.

Segment No.	Sample Name	BOD_{20} mg/l	TP mg/l	TKN mg/l	Corrected Chlorophyll <u>a</u> ug/l
0203	D3	43.29	3.10	15.00	71.81
0207	JP10	106.50	3.24	10.20	13.30
0402	WC5	63.60	1.91	5.22	55.70
0404	BYF2	519.00	4.44	12.60	39.30
0404	BYF3	279.00	2.71	3.69	16.50
0404	BYF4	83.40	1.71	2.17	39.10
0418	BV11B	16.20	0.55	0.13	13.30
0501	D2	37.28	7.80	14.82	22.11
0815	TB2	115.50	4.51	15.50	30.10
0815	TB3	66.70	1.55	6.15	235.00
0815	TB4	66.10	4.25	6.53	240.60
0815	TB4A	62.30	2.50	7.46	57.20
1003	D2	26.78	4.53	12.71	105.80
1003	D3	27.80	4.97	11.91	54.40
1005	MN3	114.50	3.40	12.00	22.50
1016	D2	5.60	0.20	7.32	11.20
1023	OR4	35.80	5.73	13.21	34.00

In this case, all model parameters were significantly different from zero. With both nutrient parameters, the joints between the two functions are at or above BOD_{20} concentrations that might normally be considered acceptable ambient stream levels (ie. 39.4 mg/l for TKN=6.0 mg/l and 35.6 mg/l for TP=1.90 mg/l). Data above these levels represent conditions where nutrient concentrations are decreasingly critical to algal biomass. This is evident in the substantially reduced slopes in the upper region equations (ie. 9 and 11). More importantly, BOD_{20} levels are at or beyond normally acceptable in stream concentrations at the joints. The region of principle concern to regulatory agencies must lie below the point where BOD_{20} levels are excessive. Thus, the lower region of the data is where acceptable conditions, and thus reasonable standards must lie. Further model development was limited to the lower region functions.

Correlation analysis of the data shows that TP and TKN are fairly highly correlated (r=0.75 in the full data set, r=0.60 in the filtered subset where TKN $\leq$ 6.0 mg/l). The magnitude of this correlation is shown in Figure 5. The significance here is that the inclusion of one of these two parameters in a model that already contains the other will supply very little additional information. It was necessary to determine which of the two parameters supplies the most information about BOD_{20}. Examination of the functions for TKN and TP for the lower region of the data (ie. TKN$\leq$6.0 or TP$\leq$1.90) showed that the TKN model, with a mean square error (MSE) of 18.5, had less error associated with its predictions that the TP model, with a MSE of 38.4. In other words, using TKN as a predictor of BOD_{20} results in a tighter fit of observed data points about the model line.

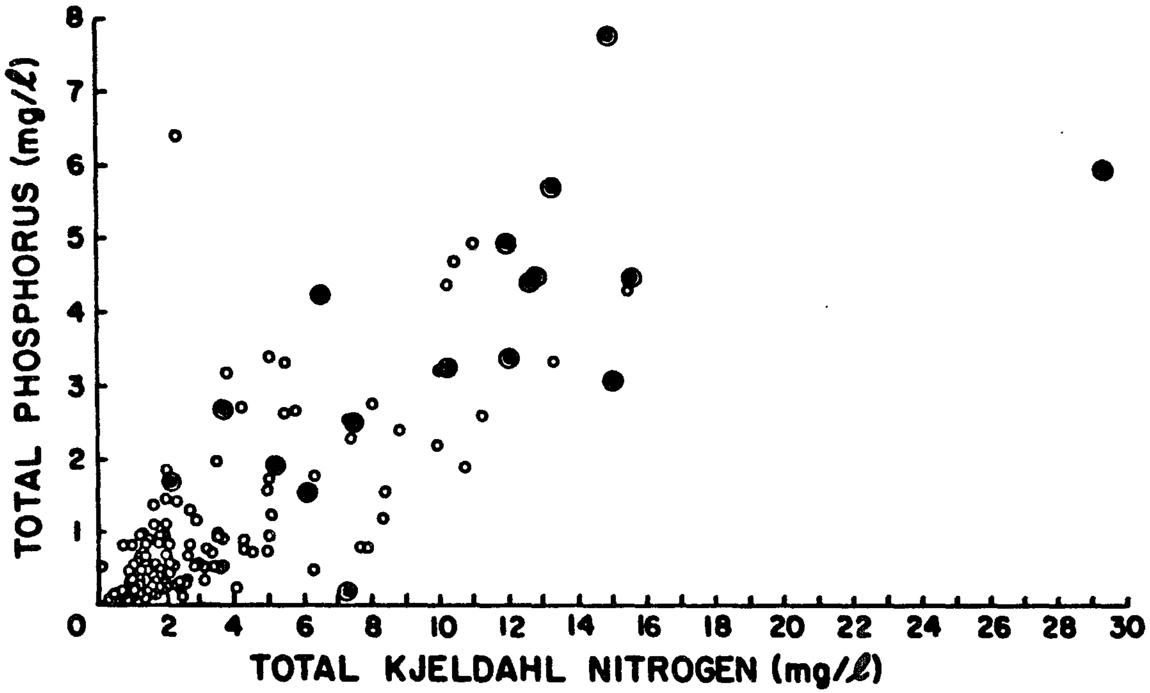

Figure 5. A plot of observed TP versus TKN in the filtered LA DEQ data set. The circled points were subsequently identified as outliers (n=262).

NITROGEN AS THE CRITICAL NUTRIENT

The regression results suggest that nitrogen is the principle critical nutrient to algal biomass and associated BOD_{20}. This conclusion is supported by examination of the distribution of TKN/TP ratios (Figure 6). The majority of streams represented in the filtered data subset had N:P ratios less than 10, the cut-off point below which nitrogen is generally assumed to be the critical nutrient. The mean TKN/TP ratio for the filtered lower region data was 5.2, marginally lower than the TKN/TP ratio in the LA DEQ data set taken as a whole. It is not surprising to see such a strong relationship between TKN and BOD_{20}. Under these conditions algal biomass will be effectively limited by the amount of nitrogen available in the environment. It was concluded that nitrogen was the critical nutrient in the vast majority of streams represented in the data set. These observations are consistent with the bulk of literature on algal growth and physiology in dynamic systems which favor nitrogen as the most critical nutrient to algal biomass (Fogg, 1959; Shelef and Halperin, 1970; Forsberg, 1977; Parker, 1977; Darley, 1982; Gromiec et. al, 1983; Jorgensen, 1983; Loucks, 1983; Whitehead and Williams, 1984).

The intercept term in equation 8 is not significantly different from zero. Therefore, it is appropriate to refit the model using a zero intercept regression. Moreover, it was noted that the variability in the BOD data suggested non-homogeneous variance, increasing with TKN concentration. A weighted, zero intercept regression was performed using a variance weight inversely proportional to the square of TKN. This type of variance relationship is typical for biological systems (Neter,

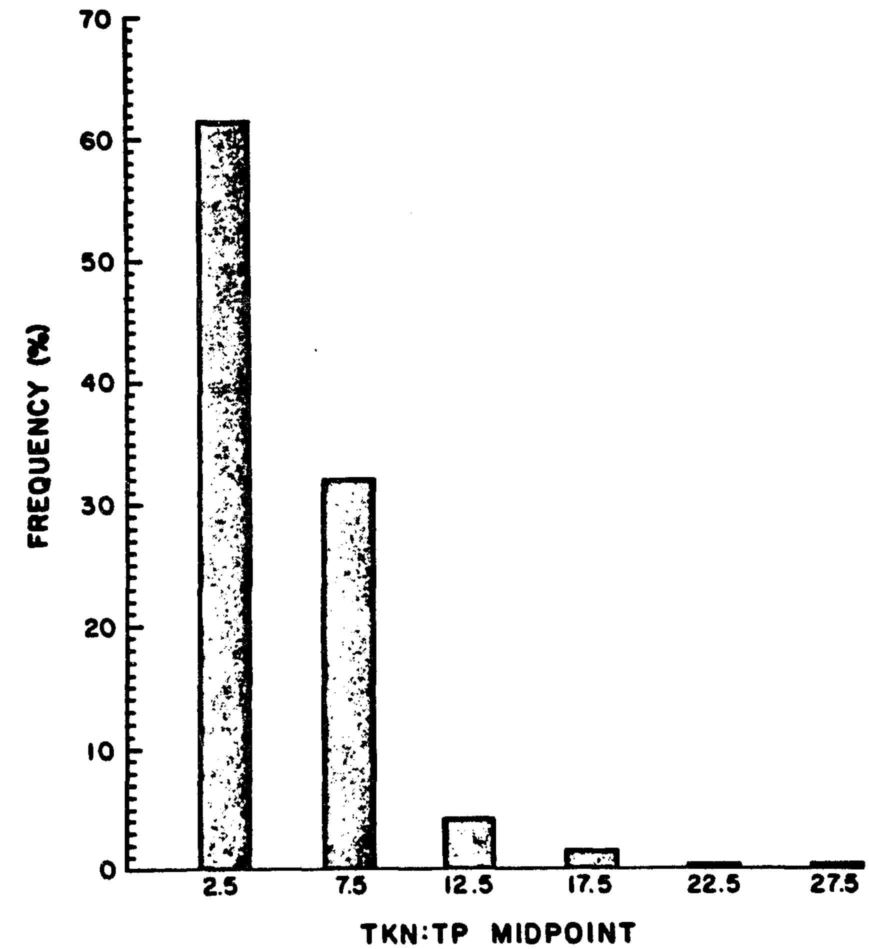

Figure 6. The distribution of TKN:TP ratios in the filtered LA DEQ data set (n=262).

Wasserman and Kutner, 1985). A listing of the SAS program used in this analysis is presented in Appendix C. This regression resulted in the following refinement of the model:

$$BOD_{20}\ (mg/l) = 7.13 * TKN\ (mg/l) \qquad (12)$$

The zero intercept condition implies that there should be no oxygen demand in the absence of TKN. This linear function, applied over the restricted region is suggested as the basic nutrient criteria model. The model predicts what the mean BOD_{20} level that may be expected to be observed for any given TKN concentration, within the constraints defining the development data set (ie. chlorophyll a greater than 10 ug/l and TKN less than or equal to 6.0 mg/l).

Figure 7 presents a comparison of model projections with the observed data over the critical region where TKN is less than or equal to 6.0 mg/l. This figure also shows the upper and lower 90% confidence bounds about the model projection line. The increased variability in the data suggests that BOD_{20} is becoming decreasingly associated with nutrients at elevated levels. As nutrients become increasingly abundant, other factors begin to limit the ability of the algal population to increase in size. The relationship between nutrients and algal based oxygen demand begins to weaken as a consequence. The fact that a lower slope was observed in upper region of the relationship indicates that beyond some nutrient level algal based oxygen demand increases at a much lower rate, as the maximum population biomass will be increasingly limited by some other factor. The piecewise regression results suggest that this upper limit is at about 40.0 mg/l BOD_{20}. The TKN based model is both consistent with theory in its general form and provides a good representation of the observed data.

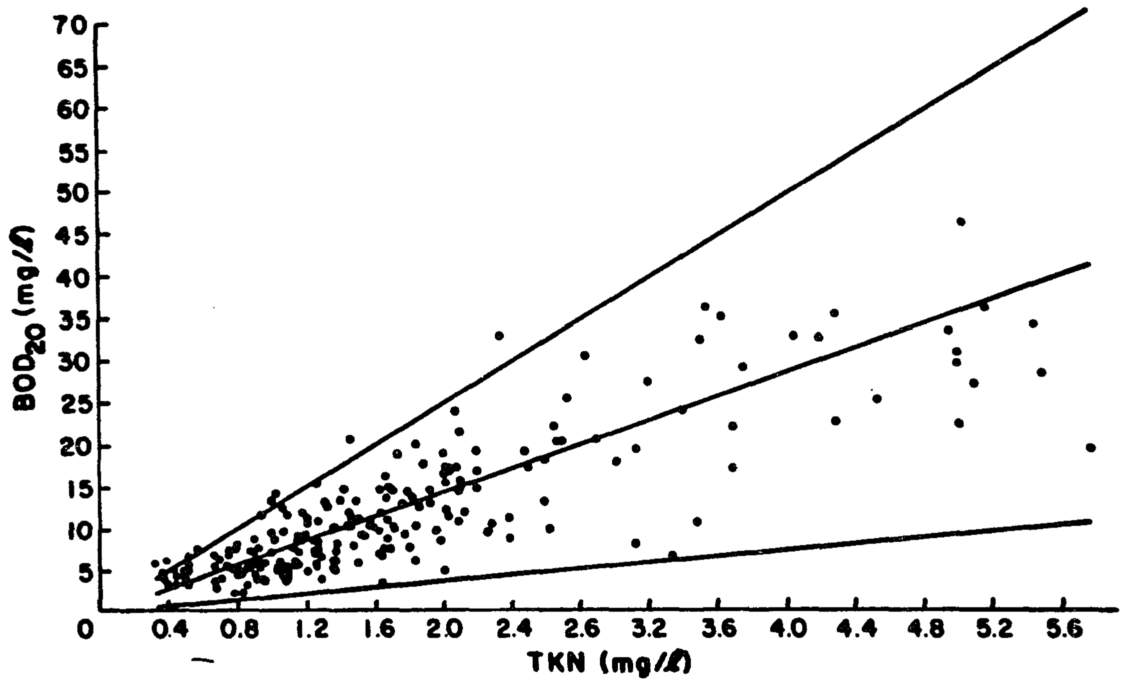

Figure 7. Comparison of the model projections with the observed data in the critical region below a TKN of 6.0 mg/l (n=225).

NATIONAL DATA SET COMPARISON

The STORET data subset, defined by the initial criteria discussed previously (ie. warm month data and chlorophyll a levels at or above 10 ug/l) and filtered for outliers, displays the same fundamental relationships among nutrients and 20 day BOD (Figures 8 and 9), albeit with a good deal more variability evident. A statistical summary of the data is presented in Table 13. Overall levels of nutrient enrichment and oxygen demand were generally lower in this data than in the Louisiana stream data and no observations were present above a TKN value of about 4.0 mg/l or a BOD_{20} value of about 14.0 mg/l.

The STORET data set offered the opportunity to examine specific nitrogenous components not represented in the LA DEQ data. One of the critical factors in a BOD-TKN relationship should be the fraction of TKN represented by organic nitrogen. Organic nitrogen was calculated as being the difference between reported TKN and total ammonia. There was far too much variability in this data to detect any relationships between organic fraction and overall level of nutrient enrichment. However, the general magnitudes remained consistent with the observed data and general theoretical expectations. For example, at a TKN level of about 1.0 mg/l the observed organic fractions ranged from about 0.05 to 0.95. The stoichiometry would suggest a range of oxygen demand from about 5.3 to 18.9 mg/l. The actual observed data ranged from about 2.0 to 13.5 mg/l BOD_{20}. It appears that the observed demand will be somewhat lower than that predicted by the stoichiometry.

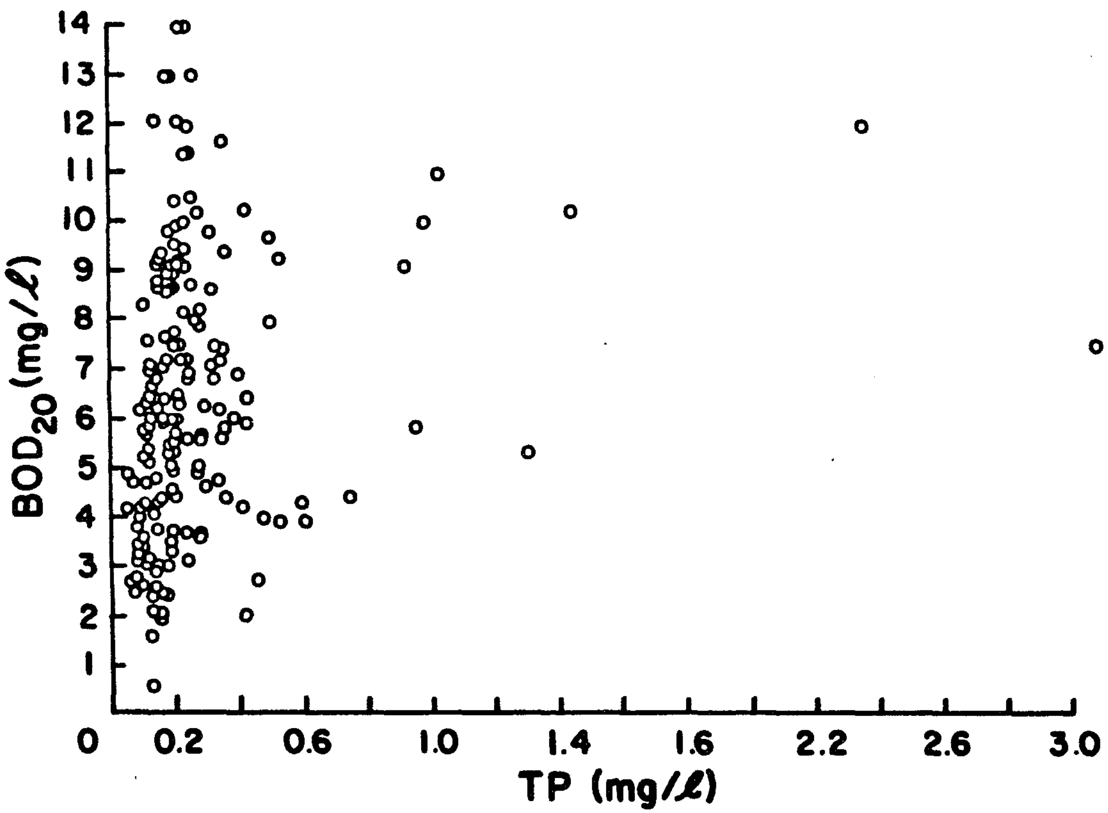

Figure 8. A plot of observed BOD_{20} versus TP in the filtered STORET data set (n=184).

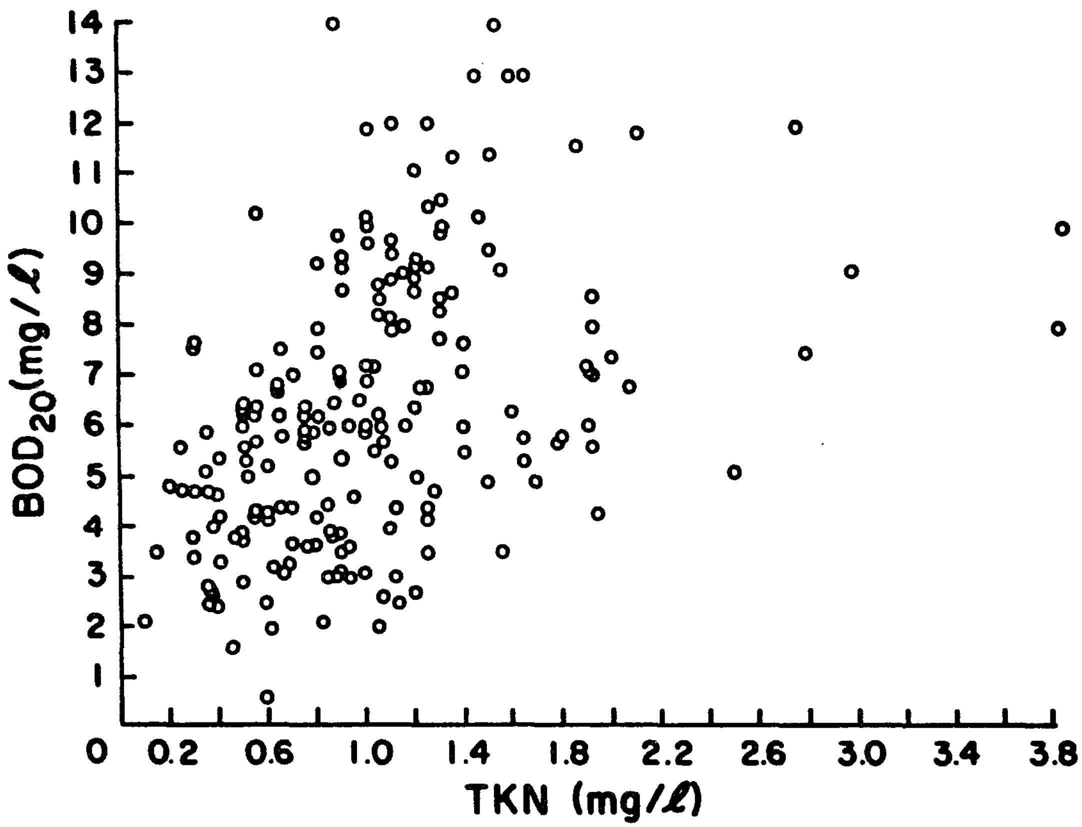

Figure 9. A plot of observed BOD$_{20}$ versus TKN in the filtered STORET data set (n=199).

Table 13. Statistical summary of the filtered STORET data with outliers discarded. (C_CHLA>10 ug/l)

Parameter	Observations	Mean	S.D.	Min	Max.
BOD_{20} mg/l	199	6.35	2.73	0.6	14.0
TKN mg/l	199	1.029	0.579	0.100	3.84
Ammonia mg/l	199	0.393	0.348	0.020	1.479
TP mg/l	184	0.262	0.321	0.050	3.079

EXAMINATION OF REGIONAL DIFFERENCES

Using the lower region criteria described previously, and considering only those states where at least 16 observations were present in the data, an analysis of covariance was performed to examine the influence of regional differences on the BOD-TKN relationship. A "No Name" state classification was included to represent observations that did not include the state of origin. Since the model is constrained to a zero intercept, any regional differences should appear as differences in the BOD_{20} - TKN slope from that fitted to the Louisiana data. Table 14 presents the results of this analysis. Minnesota and Delaware showed slopes significantly different from that of the Louisiana data at the 95 percent confidence level, while Pennsylvania showed a significantly different slope at the 90 percent level. The slopes for these three states ranged from 8.44 for Pennsylvania to 4.67 mg BOD_{20} / mg TKN for Minnesota. While these differences are statistically significant, they indicate a strong underlying phenomena with some regional variability.

The slope of the BOD-TKN relationship is theoretically based upon the distribution of nitrogen between organic and inorganic components, modified by site specific considerations such as algal population composition. The presence of a common slope among geographically diverse subsets of the STORET data suggests that there may be some common underlying characteristic that is shared by the states that exhibit a common BOD-TKN slope. Examples of factors that might be expected to effect the relationship include temperature, incident light intensity, and specific levels and compositions of nutrients in the water. Examination of the available data showed no particular pattern of

Table 14. Results of the analysis of covariance. State was the covariable in the BOD-TKN model, considering only those states having more than 15 observations. The individual state estimates are for the difference between the slope for the LA DEQ data and that for the particular state.

DEPENDENT VARIABLE: BOD20

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE
MODEL	6	22089.86	3681.64	302.05
ERROR	396	4826.72	121.19	PR > F
UNCORRECTED TOTAL	402	26916.58		0.0001

R-SQUARE	C.V.	ROOT MSE	BOD20 MEAN
0.8206	36.72	3.49	9.508

PARAMETER		ESTIMATE	T FOR H0: PARAMETER=0	PR > !T!	STD ERROR OF ESTIMATE
Louisiana slope		7.133	30.65	0.0001*	0.234
Difference between Louisiana and...	DE	-1.166	-1.69	0.0912	0.689
	MN	2.459	2.88	0.0043*	0.855
	OH	0.089	0.10	0.9218	0.903
	PA	-1.303	-2.77	0.0059*	0.470
	NO NAME	-0.293	-0.50	0.6207	0.593

* Estimate is significantly different from 0 at the 95% confidence level

differences in either physical or chemical parameters between the states where the data fits the Louisiana model, and those where a different slope is indicated.

In summary, the national data agrees well with the criteria model developed using the Louisiana intensive stream survey data. The BOD_{20} - TKN relationship identified reflects fundamental processes and phenomena common to a wide range of geographically diverse rivers and streams. The strength of the relationship is particularly significant given the uncontrolled quality and origins of the STORET data.

IMPACT OF THE MINIMUM CHLOROPHYLL REQUIREMENT

There is a good deal of uncertainty in the matter of defining a minimum chlorophyll a concentration above which waters are assumed to be algal dominated (US EPA, 1983). The choice of specific threshold concentrations for this research was somewhat arbitrary. In order to evaluate the effect of the chlorophyll a requirement, the data was evaluated without this constraint. After filtering for outliers, a TKN model was fitted to the remaining LA DEQ data in the region below a TKN of 6.0 mg/l. A total of 1342 observations, or 85% of the original data was used in this model, as compared to 225 observations, or 14% of the original data that was used in the chlorophyll constrained model. This analysis resulted in a model of the form

$$BOD_{20} = 7.32\ TKN \tag{13}$$

The mean square error (MSE) for this model was 17.74, significantly greater than that for the chlorophyll restricted model (7.20). This observation means that there was a significant increase in uncertainty in the model predictions using a larger and less restricted data set.

The important point is that while the slope of the line changed very little, the prediction uncertainty of the model increased dramatically with the removal of the chlorophyll restriction on the data and resulting six-fold increase in data points. The significance of an increase in model uncertainty will be discussed in the next chapter.

An analysis of covariance was conducted in order to further examine the differences between the two subsets of the data. The presence or absence of chlorophyll a concentrations at or above 10.0 ug/l was used as a classification criteria using all of the LA DEQ data where TKN was at or below 6.0 mg/l. This analysis showed that there was a significant difference between model lines fitted to the records with and without chlorophyll a data greater than 10 ug/l. The model for the records below the 10.0 ug/l limit was

$$BOD_{20} = 7.36\ TKN \tag{14}$$

The MSE of this model was 19.86. Thus, in systems where algal populations are minimal, as reflected in minimal chlorophyll a concentrations, a minimally higher level of oxygen demand will be expected for any given level of TKN. Within the context of practical applications, a slope of 7.36 is essentially the same as a slope of 7.13. However, the increase in error about the model is very significant from the standpoint of practical application. The imposition of the threshold chlorophyll requirement was effective in defining a more homogeneous subset of the data. Use of the model on systems where algal populations are not predominent will be inappropriate since the greater variability, and thus the extreme cases would not be well represented.

EVALUATION OF TKN AS AN ESTIMATOR OF TOTAL NITROGEN

A fundamental assumption in the development of the criteria model is that TKN will closely approximate total nitrogen (TN) in algal dominated river systems. In the presence of a significant and viable algal population it is assumed that nitrites and nitrates, which are not measured by the TKN determination but are a component of TN, will be quickly assimilated by the algae. While TN values were not available in the LA DEQ records, TN was present in a limited number of records from the STORET data set. The unfiltered STORET data showed significant correlation between TKN and TN (r=0.88, n=137), indicating that, at very least the two parameters are closely related. A regression of TKN against TN in the unfiltered STORET data gave a predictive model of the form

$$TKN = -0.033 + 0.854\ TN \qquad R^2 = 0.75 \qquad (15)$$

The intercept term was not significantly different from zero. The important point is that for the 137 observations examined, TKN represented about 85% of the TN measured. Thus, if TKN were used as an estimator of TN for these 137 observations, it would generally result in an under estimate. If the criteria model is based upon TKN data but applied using TN as the nutrient parameter, the net result would be an over estimate of the oxygen demand that will be expected for a given value of TN, and an under estimate of the maximum acceptable nitrogen concentration.

TKN and TN displayed very similar correlation values with BOD_{20} (r=0.464, n=3505 and r=0.497, n=168, respectively), further suggesting that TKN is a reasonable substitute for TN in the prediction of oxygen demand. There were no TN observations available in the filtered STORET data subset. As such, any conclusions regarding the TKN:TN or BOD:TN relationships in algal dominated stream systems would be tenuous at best. Again, since TKN appears to under estimate TN, the use of TKN as substitute for TN in the development of the model is conservative in that the model will tend to over estimate oxygen demand. This point will be discussed in a subsequent chapter.

CHAPTER VI

MODEL PREDICTION UNCERTAINTY

NEED FOR CONSIDERATION

Although the criteria model represents the trend of the observed data quite well and is consistent with theoretical fundamentals, it is apparent from Figure 7 that there is significant scatter in the observed data about the model projection line. For example, while the model predicts a BOD_{20} of 14.0 mg/l for a TKN concentration of 2.0 mg/l, the observed data ranges from about 4.0 to 24.0 mg/l BOD_{20}. Some quantitative assessment of prediction uncertainty must be made if the model is to be used effectively and with full understanding of the magnitude and implications of the uncertainty involved.

Historically, water quality standards have often ignored the variability, or stochastic behavior that is inherent in water quality measurements (Hunter, 1977; Ward and Loftis, 1983). Water quality parameters are stochastic by nature due, to a large extent, to the random character of the driving forces behind water quality, in particular precipitation and other meteorological effects (Ward and Loftis, 1983).

In a stochastic, or randomly occurring process, statistically there is a finite probability, regardless of how small, of exceeding almost any concentration of a water quality parameter. Extreme values must be considered within a context of probability and frequency of occurrence. There will always be a chance of observing a value above any given standard. Regulatory concern must lie in the frequency with which the standard is exceeded, a more realistic basis for assessment of threat to the environment. Detailed discussions of the application of basic statistical theory to the collection and evaluation of water quality monitoring data are presented by Sanders and Ward (1978), Loftis and Ward (1981), Loftis, Ward and Smillie (1983), and Ward and Loftis (1983).

The recognition of natural variability in water quality, and the need for the establishment of appropriate standards to reflect this variability are recent developments. The accurate representation of the variability of water quality parameters has been limited in the past by the lack of adequate, or appropriate baseline data (Hunter, 1977). The data set available for this study offers a unique opportunity address the significant variability of the data about the model predicted line, and incorporate this uncertainty in the establishment of nutrient standards.

ELEMENTS OF UNCERTAINTY

From the preceding discussion of autochthonous oxygen demand theory it is clear that this observed variability, or residual error may be largely attributed to a variety of site specific factors. The stoichiometry discussed previously is an idealized and somewhat simplified representation of complex processes. As such, there are several major sources of uncertainty present in the prediction of oxygen demand that will be exerted by the components of a sample. The existence of these elements of uncertainty undermine the simple use of the major stoichiometric relationships alone as the basis for nutrient criteria. Each component of uncertainty contributes to discrepancies between idealized representation and the reality of observed data. An awareness of the sources of uncertainty in the model is required if it is to be used in a rational and appropriate manner in the management of water quality.

CHEMICAL COMPOSITION. While a generalized representation of algal biomass composition was used in the stoichiometric development, it must be realized that the actual chemical composition of an algal cell at any point in space and time will be the function of a complex interaction of physical, chemical and biological factors (Fogg, 1959, 1965; Bigelow, et. al, 1977; Darley, 1982). The cell content of both phosphorus and nitrogen has been shown to be widely variable (Forsberg, 1977; Darley, 1982). The ratio of carbon to nitrogen, for example, is generally assumed to be around 6.6:1, but Steele (1974) reported values from phytoplankton ranging from 4.3:1 to 9.0:1. The potential effect of this variability on the stoichiometry is significant. If it is assumed that only the nitrogen in the generalized composition equation above varies, the reported range corresponds to values of from 11.2 to 23.4 grams oxygen required per gram organic nitrogen for the complete oxidation of biomass, as opposed to the generalized value of 19.7 grams oxygen per gram organic nitrogen. Fogg (1959) reported even greater variability in the nitrogen content of algal cells, ranging from 2.15 to 11 percent of dry weight.

BACTERIAL ASSIMILATION AND GROWTH. The stoichiometric representation of decomposition assumes the complete oxidation of algal biomass to mineralized forms. However, in any bacterial decomposition, it must be recognized that some of the organic material will be converted to bacterial biomass. Rittmann and Langeland (1985) reported a 60 percent conversion of organic matter to bacterial biomass, with a resulting expected oxygen requirement of 8.5 grams for each gram of organic nitrogen decomposed. The same study reported a value of 4.1 grams of oxygen required for the oxidation of each gram of ammonia nitrogen similarly decomposed. While much of the resulting bacterial biomass will be subsequently decomposed in a 20 day BOD determination, there will be some fraction of the nitrogen that will not be involved in oxidation processes. This factor will obviously result in significantly lower observed oxygen demand than that expected from the stoichiometry.

DISTRIBUTION OF NITROGEN AMONG THE ORGANIC AND INORGANIC FRACTIONS. As discussed previously, the distribution of nitrogen between the organic and inorganic components will have a significant effect on the expected oxygen demand. The actual organic fraction that might be expected in any sample will vary with the level of nutrient enrichment. At very low nutrient levels, where nutrients are the principal limiting factor it would be expected that algae would assimilate available nitrogen very rapidly, as they have been observed to do in nutrient deficient chemostat studies (Darley, 1982). Under these conditions, nearly all of the nitrogen may be expected to be in the organic fraction. As nutrient levels increase, other factors such as crowding and light availability begin to limit algal density and nutrient uptake. It would be expected that a greater proportion of the nitrogen in the inorganic ammonia fraction under such conditions. As the contributing processes to nutrient assimilation and limitation are typically non-linear and hyperbolic (Steele, 1974; Mauersberger, 1983), it is reasonable to assume that the relationship between inorganic nitrogen fractions and total nitrogen levels would display a similar form. This may well contribute to the two phase trend observed in the data with increasing nutrient levels. The STORET data for this study proved to be far too variable to confirm this point.

A stream sample is a snapshot of a dynamic system. The particular mix of nitrogenous components may be expected to change through time as the various, often transient factors effect the uptake and production of available forms, as well as the growth, death and very composition of algal cells. It has been stated by Darley (1982) that standing stocks of nutrients in the water column are generally a poor indicator of nutrient status since cellular concentrations vary considerably. The organic nitrogen fraction would, then, be expected to be a variable and fairly uncertain parameter.

MEASUREMENT ERROR. Crane (1981) surveyed the literature on the reliability of the BOD_{20} determination and reported a general level of accuracy corresponding to a coefficient of variation of about 15%. Although 20 day BOD is utilized as an estimator of ultimate BOD, oxygen demand may be exerted well beyond 20 days depending on the reaction rates of the sample constituents. More complex materials require longer periods for complete decomposition. Additionally, since nitrogenous oxygen demand is significant in algal decomposition, the time lag typically observed in the development of an adequate population of nitrifying bacteria in the BOD sample bottle may result in incomplete oxidation of the inorganic nitrogen forms by the 20th day. These effects will generally result in the under estimation of ultimate demand.

In any laboratory nutrient determination there is some component of error which stands between the measured concentration and the actual level of material in the sample. Some determinations are more reliable than others depending upon the particular nutrient species and specific determination technique used. For example, Jenkins (1977) reported coefficients of variation (C.V.'s) for TKN determinations in the range of 25.7 to 104 percent. Ammonia determinations had C.V.'s in the 5.3 to 69.8 percent range. Clearly, measurement error has the potential for introducing significant uncertainty into any modeled relationship, particularly where a variety of data sources and laboratory methodologies are involved, and quality control information is lacking.

MODEL STRUCTURE. As discussed above, the stoichiometry presented is a simplified representation of a very complex process. The application of a simplified model introduces prediction error resulting from processes and relationships that are not included in the model structure. If the model structure has accounted for the principal component processes within the system, the sum effect of the model error will be relatively minor. The decision regarding model adequacy must ultimately be made by the user within the context of actual application.

MANIFESTATION OF UNCERTAINTY

It is unlikely that the measured oxygen demand exerted by the constituents of a sample will agree with that expected from the stoichiometry alone. From the discussion presented, it is apparent that, on the average, measured oxygen demand, as BOD_{20} will probably be lower than that predicted by simple consideration of chemical composition. The theoretical considerations suggest that the relationship between oxygen demand and nitrogen content will be modified by a variety of predominantly random effects. The random component of the relationship will encompass natural variability in all of the myriad environmental and biological factors that act in concert to define an algal population at any point in space and time. If the fundamental processes can be adequately described by a model, then the random components will be manifested as residual error distributed about some mean response corresponding to the model prediction.

DEVELOPMENT OF THE PROBABILISTIC MODEL

For the objectives of this research, the utility of uncertainty analysis lies in the estimation of probability of exceedence of established BOD_{20} standards. Given a specific BOD_{20} standard, the probability of exceedence may be estimated for any given TKN concentration using the predicted observation probability distributions. Similarly, a TKN standard may be estimated given a BOD_{20} standard and an acceptable frequency of exceedence. This latter case is expected to represent the principle application of the criteria model.

The uncertainty associated with a zero-intercept model prediction of individual observations may be expressed as the standard error of the prediction (Montgomery and Peck, 1982),

$$SE_p = [\ MSE\ (1 + (TKN^2\ /\ USS_{TKN})\ ]^{0.5} \qquad (16)$$

where SE_p = Standard error of the prediction

MSE = Mean square error

TKN = TKN value for which the prediction is made

USS_{tkn} = Uncorrected Sum of squares of TKN in the data set

The criteria model predicts a mean BOD_{20} value for any given TKN concentration. However, there will be variability in the observed data about this model prediction line, and thus uncertainty in the model prediction. The standard error of the prediction is the standard deviation of the BOD_{20} observations that will be expected about any given mean BOD_{20} value predicted by the model. Prediction error is proportional to the mean square error term. This is why MSE is used in assessing the best model fit.

The distribution of expected BOD_{20} observations for any given TKN concentration is defined by the mean prediceted BOD and the SE_p. This distribution is a continuous normal function. Integration under the curve between any two BOD_{20} values will yield the probability of an observation falling between those two values. Thus, if the function is integrated between any specific BOD_{20} value and positive infinity, then the result will be the overall probability of an observation exceeding the specific BOD value. In this manner, it is possible to calculate the probability of exceeding any BOD standard under any given TKN concentration. Appendix C contains a discription of this integration.

Figure 10 presents a nomograph of model predicted probabilities of exceedence for various BOD_{20} levels corresponding to TKN concentrations within the restricted region under 6.5 mg/l. Appendix C contains a listing of the SAS program used to develop this nomograph. Figure 10 is the essence of the probabilistic nutrient criteria model. This representation of the model permits a comparison of various risks of exceedence of a given BOD_{20} standard that would be expected under any TKN concentration. For example, given a TKN concentration of 2.0 mg/l, there will be about a 79% probability of exceedence of a 10 mg/l BOD standard, but only about a 15% probability of exceeding a 20 mg/l standard. Conversely, given a 25 mg/l BOD_{20} standard, and an allowance for 10% exceedence, the model requires a maximum TKN limit of 2.4 mg/l. This last example demonstrates what is expected to be the principle application of the model: the definition of maximum allowable nutrient levels in order to satisfy previously determined BOD concentration and exceedence standards.

The choice of an acceptable exceedence level will be crucial to the prediction of a nitrogen standard. A higher level of exceedence will result in a higher corresponding nutrient standard. Any combination of BOD standard and level of exceedence may be tested to evaluate the marginal effects of increasing or decreasing risk levels. As an example, given a BOD standard of 30 mg/l, an allowable exceedence level of 10% yields a TKN limit of about 2.8 mg/l. If the risk of exceedence were to be lowered to 5% the TKN limit would be reduced to about 2.6 mg/l.

Figure 11 presents the same information contained in the nomograph in Figure 10, but limited to the most commonly used upper confidence levels of 95 and 90 percent. In other words, the upper line model predictions in Figure 11 may be expected to be exceeded 2.5 percent of the time, while the lower line predictions will be exceeded approximately 5 percent of the time. Model predictions in this figure are identical with those presented in Figure 10.

The examination of the model predictions in terms of probabilities of exceedence focuses the attention on the prediction of extreme events. Consideration of mean predicted conditions alone is of limited value in management of aquatic environments. It is the occurrence of extreme events that must be addressed in effective management. The developed nutrient criteria model provides this crucial information.

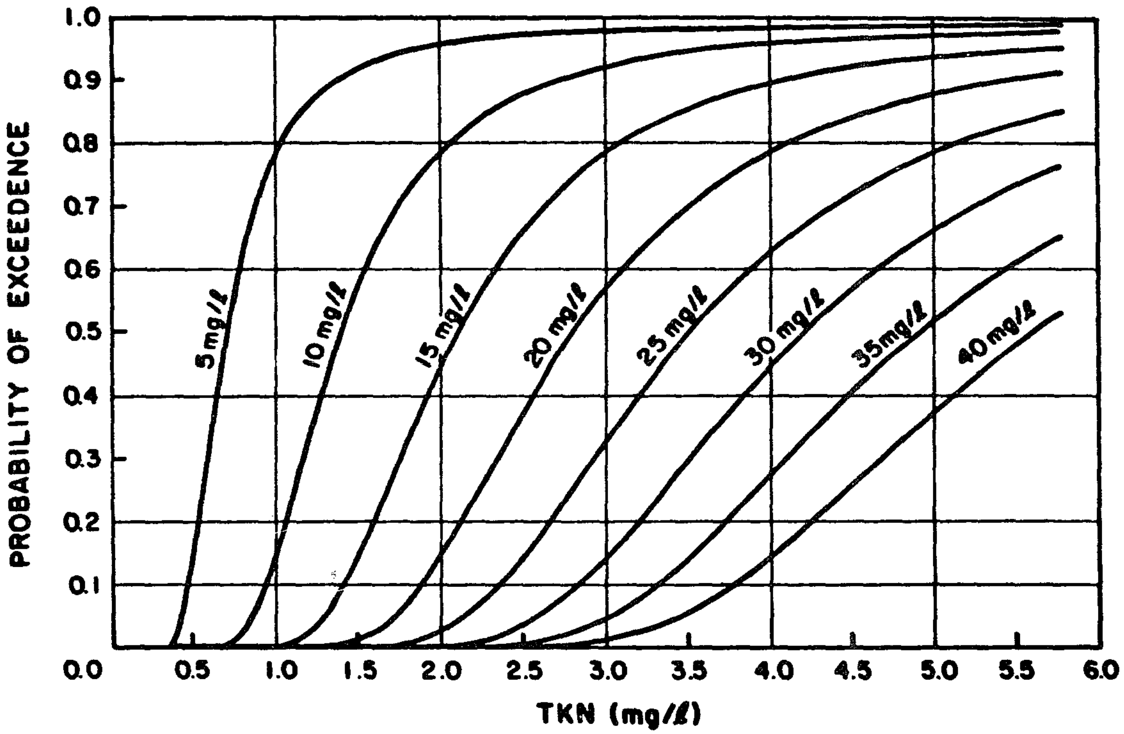

Figure 10. A nomograph representing model predicted probabilities of exceedence for a range of BOD_{20} standards from 5 to 40 mg/l as a function of TKN concentration.

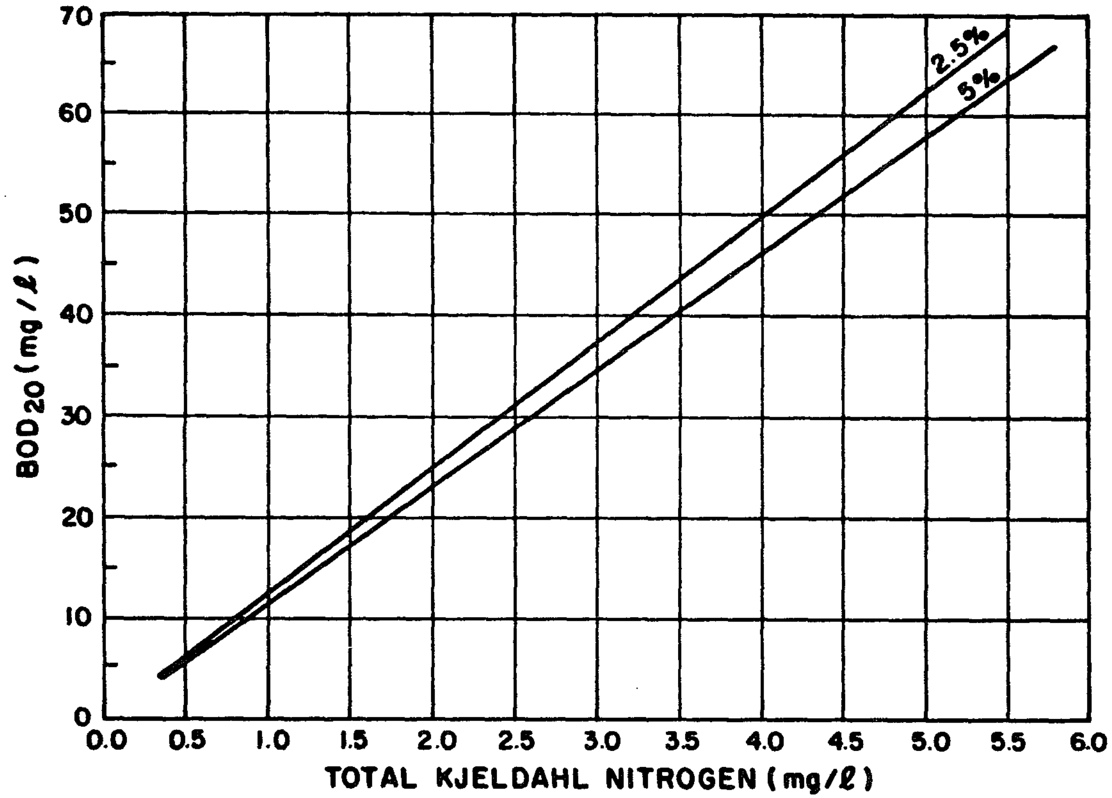

Figure 11. Model predictions of BOD_{20} levels that will be exceeded 2.5 or 5 percent of the time under any TKN concentration up to 6.0 mg/l.

CHAPTER VII

UTILITY AND APPLICATION OF THE CRITERIA MODEL FOR THE MANAGEMENT OF WATER QUALITY

This chapter deals with the application of the developed nutrient criteria model. The model is intended to establish maximum allowable total nitrogen concentrations as a function of maximum allowable BOD_{ult} and some acceptable risk of BOD exceedence. The model acts as a supplement to the usual waste load allocation process.

GENERAL APPLICABILITY

The probabilistic nutrient criteria model is meant to serve as a means of rationally establishing in-situ nitrogen standards for rivers and streams dominated by autochthonous processes. The model relates to nitrogen levels in streams where nutrient material from external loading is quickly assimilated by the resident algal populations. Under these circumstances, algal processes present the principal threat to the health of the system in the form of potential oxygen demand in the event of a population collapse.

Conversely, the nutrient criteria model is inappropriate where physical conditions preclude the existence of a vigorous algal population and the subsequent dominance of autochthonous processes. The principal physical factors of concern here are temperature and light availability. Under these circumstances the relationship between nitrogen and BOD is much weaker and the concern over nitrogen in the system shifts away from eutrophication and algal related processes.

INFORMATION CONTAINED IN THE CRITERIA MODEL

The probabilistic nutrient criteria model provides an estimate of the maximum oxygen demand that would be expected for a given level of oxidizable nitrogen in a stream sample where algal processes may be expected to dominate. The actual net oxygen demand exerted by an algal population will be dependent on a complex interaction of photosynthetic activity, growth, and mortality. The uncertainty incorporated in the model takes the natural variability of stream conditions into account, giving a rational estimation of the uncertainty that will be associated with real observations.

The model emphasizes the worst case situation by expressing the model predictions in terms of risk of exceedence of maximum allowable BOD values. Moreover, the degree of conservativeness may be adjusted to suit site specific requirements and state regulations through the selection of acceptable probabilities of exceedence.

ESTABLISHMENT OF STANDARDS

The principal value of the developed criteria model is to allow stream managers to determine where the upper limit of acceptable total nitrogen concentrations will be for a given level of acceptable oxygen demand and risk of it's exceedence.

The nutrient criteria model is meant to supplement the establishment of BOD standards in protecting the stream from oxygen depletion. The application of the model requires that a total maximum daily load (TMDL) for BOD be first established for a point of discharge using the usual waste load allocation procedures. The TMDL is based upon an estimate of the maximum ultimate BOD that the stream may assimilate under the specified conditions of flow and season for a specified point in a stream. The ultimate BOD value thus calculated is used as the input information on maximum allowable BOD for the nutrient criteria model. The criteria model prediction is therefore based on the stream system analysis conducted through the waste load allocation process. In this manner the model incorporates site specific conditions into the predicted standard.

While the waste load allocation process can provide the information on the maximum acceptable BOD standard concentration, risk of exceedence must be determined based on local conditions and priorities (Schaeffer, et. al, 1980; Loftis, Ward and Smillie, 1983; Ward and Loftis, 1983; Whitehead and Williams, 1984). There is some consensus in the literature that a 10% exceedence level is reasonable in natural systems (Schwartzkopf and Hergenrader, 1978; Schaeffer, et. al, 1980; Ryding, 1981). It is recommended that a more conservative level of 5%, corresponding to an upper 90% confidence interval would be more appropriate for the adequate protection of stream systems. The final decision must be left up to regulatory agencies.

In practice, the model predicted standards must be interpreted in terms of total nitrogen, despite the fact that the TN versus TKN observations presented in Chapter V suggest that TKN will generally under estimate TN in most situations. This requirement insures that significant concentrations of nitrites and nitrates will be included in the analysis. In the setting of standards, it must be assumed that nitrates in discharges will be quickly assimilated into organic material upon entering the stream. There will, of course, be some lag period between introduction and assimilation, depending on a variety of site specific conditions.

With additional data on the relationship between TKN and TN it would be possible to restate the model less conservatively. The very limited data available suggests that TKN represents about 85% of the TN present in a sample. If this or a similar relationship were substantiated by data from algal dominated systems it could be applied to convert the TKN axis in Figures 10 and 11 to TN. The result would be larger allowable nitrogen levels for any given BOD_{20} standard required. As an example, for a 25 mg/l BOD_{20} and 5% exceedence standard Figure 10 indicates a corresponding nitrogen standard of 2.2 mg/l. If TKN is only 85% of TN, the TN standard would be 2.6 mg/l. The evidence regarding the relationship is not sufficient to justify it's use at this time since there was no indication that the data used to develop it represented algal dominated systems. This is an area where future data collection and evaluation efforts are needed.

Predicted stream nutrient standards must apply to the stream itself. That is, since the development data set consists of ambient stream samples, the model is only applicable to similar conditions, specifically stations outside of waste discharge mixing zones. Thus, model derived standards must apply to the total nitrogen content at ambient stream monitoring stations. The total nitrogen content measured immediately downstream of a mixing zone would be expected to be the sum of the ambient upstream contribution plus that of the discharge. This is point at which the model would be applied in a waste load allocation.

The nitrogen standard derived from the model represents the maximum allowable total nitrogen that would be required to ensure that BOD_{ult}

levels are maintained at or below the critical level the bulk of the time. The model projects the worst case situation of algal manifestation and population collapse. Most of the time, actual algal manifestation and oxygen demand will be below the value predicted. As with any model, some discretion must be exercised by the user in evaluating model projections. Where local conditions contradict model assumptions, rational allowances must be made.

ESTIMATION OF REQUIRED NUTRIENT REDUCTION

Use of the model to assess required nutrient reductions to meet set BOD standards is important. The model has been shown to be consistent with the accepted theory regarding oxygen demand in streams. Model projections agree well with literature data on oxidation of organic material, and the model seems to represent widely varying geographic data well. Fundamental and ubiquitous processes are being represented.

Where excessive nitrogen levels are found, an inventory of all stream loading sources would be required to identify the most appropriate strategy for reduction and control. The model will provide an estimate of the level of total nitrogen which must be attained, but the partitioning and control of nitrogen sources must be determined on a case by case basis.

ADVANTAGES OF THE PROBABILISTIC MODEL OVER THE CONVENTIONAL WASTE LOAD ALLOCATION APPROACH TO NUTRIENT STANDARDS

The probabilistic model offers significant advantages over the current available waste load allocation approach to nutrient control as described in Chapter II. The two strategies differ primarily in their manner of characterizing processes in the environment. The conventional approach attempts to precisely describe a complex system of interacting processes while the probabilistic approach attempts to characterize these processes in terms of the lumped "average" net effect observed in the phenomena.

A comprehensive kinetic stream model of the aerobic nitrogen cycle requires 22 constants and 10 initial concentrations to describe seven nitrogen components and three bacterial species at any point in time (Gromiec, et. al, 1983). Even a simplified "desk top" model of this sort involves 7 constants and 3 initial concentrations to calculate the effect that nutrients and algae will have on daily dissolved oxygen (Driscoll, et. al, 1984). Some proportion of the coefficients may be practically unmeasurable in any realistic application, and literature values are often used instead. From the discussion regarding sources of uncertainty, it should be apparent that the estimation of algal kinetic rates, along with projection of biomass in terms of chlorophyll a, and the subsequent incorporation of these estimates into a complex model as required in the conventional waste load allocation approach has significant potential for error. It has been shown that error in the specification of model parameter coefficients may have a much greater impact on model prediction error than any noise that may exist in the input data (Finney, et. al, 1982). Moreover, it has been recognized that model coefficient estimation is particularly difficult where algal processes dominate (Whitehead and Williams, 1984). Even with an adequate data base, the present state-of-the-art in nutrient modeling at this level of complexity affords poor to fair reliability at best (Gromiec, et. al, 1983).

The probabilistic nutrient criteria model incorporates both a sound theoretical foundation, as well as the strength of an observed robust relationship between readily measurable parameters in a diverse database. The data requirements for it's application are straightforward and readily obtainable. The probabilistic nature of the model insures that the ubiquitous variability that characterizes natural systems will be both acknowledged and quantified. All evidence suggests that the fundamental relationship will be valid across widely varying geographic areas. Where regional differences are present, their effect is that of a simple respecification of the model parameters.

LIMITS OF APPLICATION

A fundamental assumption in the use of the model is that TKN will be a good estimate of the total nitrogen content of the system. Where sources of oxidized forms, such as nitrates are significant, it must be assumed that they will be quickly assimilated into algal biomass, and thus present the potential for oxygen demand. This fundamental assumption of the model requires that the model be applied only to those streams where algal populations are likely to flourish, otherwise inappropriate standards will be predicted.

The existence of physical conditions which preclude, or significantly limit the development of algae in a stream will place the stream outside of the domain of this model. Such conditions might include, but not be limited to:

- High turbidity due to inorganic suspended material such as silt
- High levels of colored colloidal material
- Light limitation due to shading by trees or other shoreline vegetation.

As an example, nitrate discharges into a stream with low turbidity would be expected to be quickly assimilated by algae and become a component of the overall oxygen demand potential. On the other extreme, in a river like the lower Mississippi, where mineral turbidity effectively precludes algal growth, nitrogen enrichment, regardless of the component mix would not present an immediate potential for oxygen depletion, and the use of this model for setting nitrogen standards would not be appropriate.

In the projection of conditions expected in the wake of nutrient reduction implementation, some consideration must be given to the nature of nutrient constituents in a stream. Where complex or refractory nitrogenous materials are present, their resistance to decomposition and subsequent assimilation into the algal biomass will limit their contribution to BOD. As such, reduction in such materials would not be expected to have nearly as significant an impact on BOD_{Ult} reduction as would a similar reduction in ammonia.

While nutrients are of concern in streams, there is a greater overall interest in their impact on lakes in Louisiana. It must be recognized that this study's findings are not, in any way directed at this problem. Lakes may be expected to present an entirely different set of processes, at the heart of which is the difference in detention times involved. Where detention times in lakes are sufficient for the development of significant populations of nitrogen fixing organisms, phosphorus will likely become the nutrient of critical concern. Thus, in streams that discharge into lakes, phosphorus concentrations may be of concern to the stream manager, but for more indirect reasons than nitrogen.

It should be noted that the model was developed using data reflecting conditions where nitrogen is predominantly the critical nutrient. It is expected that application of the nutrient criteria model to phosphorus critical systems would result in overly conservative standards, the enforcement of which would force the system to a nitrogen critical condition. Although there is no evidence to suggest that the same relationship will not hold in streams where phosphorus is the apparently critical nutrient, and in fact the model appears to be quite robust, some caution is recommended.

CHAPTER VIII

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Nitrogen, as measured by total Kjeldahl nitrogen (TKN) was identified as the principal nutrient of concern in the prediction of algal based, or autochthonous oxygen demand in the rivers and streams represented in both the LA DEQ and STORET data sets. This observation is consistent with the theoretical stoichiometry behind biochemical oxygen demand, and significant in that phosphorus has traditionally been the target nutrient for eutrophication control. A fundamental assumption in the application of this research is that TKN will be a close estimate of TN in algal dominated systems.

The linear model describing the relationship between TKN and autochthonous BOD_{20} in the region bounded at a TKN value of 6.0 is the basis for the developed nutrient criteria model. The lower region is the zone of principal concern to regulatory interests since it is where acceptable BOD conditions are found. Moreover, the upper region is described by a much flatter line, indicating that algae are much less responsive to changes in nitrogen above a level of about 6.0 mg/l TKN. It appears that above this level of enrichment other factors, such as physical forces in the environment become critical to algal biomass development.

The same overall relationship between BOD_{20} and TKN was evident in the STORET data as was observed in the LA DEQ data. Among the states well represented in the filtered STORET data, Ohio and a lumped "No State Reported" group showed no significant difference in the slope of the model line from that for the LA DEQ data. Delaware, Pennsylvania and Minnesota showed significantly different slope values from that of the LA DEQ data model. There was insufficient data to draw any conclusions regarding the sources of the observed regional differences.

It was observed that, among the limited data available, TN and TKN were closely correlated, with TKN generally representing about 85% of TN in a sample. There were no TN records available to corroborate this observation in algal dominated streams. Prudency requires the assumption that TKN is a close estimator of TN in the absense of data to the contrary. The model prediction is interpreted as total nitrogen to insure that potential impacts from significant nitrite and nitrate components are considered. The use of TN in the application of the model developed using TKN is conservative in the prediction of associated oxygen demand. With specific data on the relationship between TKN and TN, a less conservative model may be specified. Inadequate historical data is the primary limitation in this regard. Ultimately, it is recommended that comprehensive and reliable TN data be collected in order to respecify the model in terms of a BOD-TN relationship.

Examination of the minimum chlorophyll a requirement in the model development data sets indicated that this constraint had a definite effect on the resulting model. Recalibration of the model yielded a marginally higher model slope, meaning that there was somewhat more oxygen demand represented per unit TKN in the data where chlorophyll a was below minimal levels than in the data where chlorophyll a was above 10.0 ug/l and algae were dominent. The recalibration also yielded a much greater level of model uncertainty than the chlorophyll restricted model. It was concluded that the differences in mean predicted oxygen demand were insignificant from a practical standpoint, but the dramatic increase in model uncertainty was reflecting a much more heterogeneuos sample population. The imposition of a minium chlorophyll requirement was effective in defining a more homogeneous subset, reflecting conditions associated with algal dominance.

Model prediction uncertainty was significant and required the expression of model projections in terms of probabilities of exceedence of given BOD_{20} standards. The developed probabilistic nutrient criteria model provides a supplement to the waste load allocation (WLA) process for the protection of rivers and streams from the adverse consequences of algal related oxygen demand. The usual waste load allocation process provides an estimate of the maximum BOD_{ult} allowable for any point in a stream. This BOD standard incorporates site specific considerations into an estimate of the assimilative capacity of the stream. The probabilistic nutrient criteria model predicts a maximum total nitrogen concentration that may be expected to be associated with the specified BOD standard.

The incorporation of risk in the model structure is vital since the level of uncertainty in natural waters is characteristically significant. Moreover, the incorporation of risk allows the use of the model over a range of risk levels, tailored to meet local regulations and site specific requirements.

The model can only provide an estimate of the total amount of nitrogen that may be in the water column to insure that algal based oxygen demand remains within specified standards. Where concentrations are in excess of those required by the model, an inventory of loading sources must be conducted to identify and assess strategies for reduction.

The probabilistic nutrient criteria model provides a significant advantage over the presently available techniques for nutrient impact assessment in the WLA process. By using large historical databases and a probabilistic approach, fundamental processes are characterized with a minimum requirement for site specific support data and the estimation of kinetic formulations. The model is firmly based in the reality of measurable and observed data.

The demonstrated strength of the modeled relationship over a range of very diverse data suggests that the model will be widely applicable. The processes represented tend to be ubiquitous, minimizing reliance on site specific parameter estimations, and maximizing the value of large historical databases. Given the limitations of using historical data from diverse sources, the strength of the observed BOD-nitrogen relationship is impressive. The biggest limitation to wide-spread application is the simple lack of adequate stream data. All evidence suggests that the modeled relationship is quite robust and will not change substantially as additional verification data becomes available in the future.

RECOMMENDATIONS

FUTURE MODELING EFFORTS. Although the model developed in this study seems to represent the data well, a general re-examination of the relationship between allochthonous BOD and nutrients in the State's streams should be undertaken at some point in the future when a more substantial mass of suitable data is available. In particular, it is recommended that total nitrogen data be routinely collected so that the relationship between TN and TKN may be better defined and understood. Ultimately, it would be ideal to respecify the model directly in terms of TN. It would be expected that the general structure of the model will prevail, but the model coefficient(s) may require adjustment. Re-examination of the calibrated nutrient criteria model developed in this investigation with a larger data set may well result in a modest decrease in the uncertainty of the model's predictions.

Given the theoretical importance of the organic nitrogen fraction, as defined in Chapter III, there is a definite need for future research into the relationship between this parameter and general level of nutrient enrichment. Specifically, organic nitrogen data should be collected coincident with TN and TKN data. One of the difficulties in examining the STORET data was that a large proportion of the reported ammonia concentrations were found to be greater than the TKN concentrations for the same observation. These records were not considered in examining organic nitrogen fraction, but subtler inaccuracies could well exist in the remaining records.

WATER QUALITY MONITORING. In the general context of future water quality monitoring practices to support further development of the probabilistic nutrient criteria model there should be a standardized suite of parameters collected in conjunction with all sampling programs. These parameters should include, but not necessarily be limited to:

- BOD_{20}
- Total Nitrogen
- Total kjeldahl nitrogen
- Ammonia nitrogen
- Nitrite/nitrates
- Total phosphorus
- Ortho-phosphorus
- Dissolved oxygen
- Chlorophyll a (Corrected for pheophytin)
- Secchi transparency
- Tubidity
- Temperature

Routine collection of these parameters will permit both the application of the nutrient criteria model described in this report, as well as providing a consistent data base on rivers and streams.

The existence of large historical databases affords the researcher a potentially invaluable resource. Every effort should be made on the part of supervising agencies to insure the utility and quality of the records.

BIBLIOGRAPHY

Baker, L., P. Brezonik, and C. Kratzer, 1981
Nutrient Loading - Trophic State Relationships in Florida Lakes., Florida Water Resources Research Center, Research Project Technical Completion Report, Publication No. 56, Project No. A-038-FLA, 126 p.

Bigelow, J.H., J.G. Bolton, and J.C. De Haven, 1977
Assessment of Algae Blooms, A Potential Ecological Disturbance., Protecting an Estuary From Floods - A Policy Analysis of the Oosterschelde, Vol. IV, R-2121/4-NETH, Rand Corp., Santa Monica, Calif., 81 p.

Crane, S.M., 1981
Reliability Analysis of BOD Kinetics in a Small Southern Stream Governed by the Discharge of an Oxidation Pond. Master's Thesis, Louisiana State University, 1981, 124 p.

Darley, W.M., 1982
Algal Biology: A Physiological Approach.
Blackwell Scientific Publications, Oxford, UK, 168 p.

Driscoll, E.D., J.L. Mancini and P.A. Mangarella, 1984
Technical Guidance Manual for Performing Waste Load Allocations, Book II Streams and Rivers, US EPA, Office of Water Regulations and Standards, EPA 440/4-84-022.

Dubois, D.M., 1978
Catastrophe Theory Applied to Water Quality Regulation of Rivers., State-of-the-Art in Ecological Modeling, v. 7:751-758.

Finney, B.A., D.S. Bowles and M.P. Windham, 1982
Random Differential Equations in River Water Quality Modeling, Water Resources Research, v. 18, n. 1, pp 122-134.

Fogg, G.E., 1959
Nitrogen Nutrition and Metabolic Patterns in Algae, in Utilization of Nitrogen and Its Compunds by Plants, Symposia of the Society for Experimental Biology, n.13, pp 106-125.

Fogg, G.E., 1965
Algal Cultures and Phytoplankton Ecology. University of Wisconsin Press, Madison and Milwaukee, 126 p.

Forsberg, C., 1977
Nitrogen as a Growth Factor in Fresh Water, Progress in Water Technology, v.8, n. 4/5, pp 275-290.

Forsberg, C. and S.O. Ryding, 1980
Eutrophication Parameters and Trophic State Indices in 30 Swedish Waste-Receiving Lakes, Arch. Hydrobiol., v. 89, n. 12, pp 189-207.

Gordon, D.M, C.M. Finlayson, and A.J. McComb, 1981
Nutrients and Phytoplankton in Three Shallow, Freshwater Lakes of Different Trophic Status in Western Australia. Aust. Journ. Mar. Freshwater Res., v. 32, 541 - 553.

Gromiec, M.J., D.P Loucks, and G.T. Orlob, 1983
Stream Quality Modeling, in Mathematical Modeling of Water Quality: Streams, Lakes and Reservoirs, G.T. Orlob, ed., Wiley-Interscience, pp.176-226.

Hunter, J.S., 1977
Incorporating Uncertainty into Environmental Regulations. Nat'l Acad. of Sciences Report: Analytical Studies for the US EPA; Vol. IV, Environmental Monitoring, Nat'l Academy of Sciences.

Jenkins, D., 1977
The Analysis of Nitrogen Forms in Waters and Wastewaters, Progress in Water Technology, v.8, n.4/5, pp 31-53.

Jorgensen, S.E., 1983
Modeling the Ecological Processes, in Mathematical Modeling of Water Quality: Streams, Lakes and Reservoirs, G.T. Orlob, ed., Wiley-Interscience, pp. 116-149.

Kautz, R.S., 1980
Fish Populations and Water Quality in North Florida Rivers., unknown - Office of Environmental Services, FL Game & Freshwater Fish Commission, Tallahassee, FL (904) 488-6661.

Kopf, V.W., 1983
Investigations of the Dynamic of Chlorophyll Concentration in Natural Populations of Phytoplankton, Arch. Hydrobiol., v. 98, n. 2, pp 173-180.

Loftis, J.C. and R.C. Ward, 1981
Evaluating Stream Standard Violations Using a Water Quality Data Base. Water Resources Bulletin, vol. 17, no. 6, pp 1071-1078.

Loftis, J.C.,R.C. Ward and G.M. Smillie, 1983
Statistical Models for Water Quality Regulation. Journal of the Water Pollution Control Federation, vol. 55, no. 8:1098-1104.

Loucks, D.P., 1983
Models for Management Applications, in Mathematical Modeling of Water Quality: Streams, Lakes and Reservoirs, G.T. Orlob, ed., Wiley-Interscience, pp. 468-502.

Louisiana Department of Environmental Quality, 1985
Louisiana Wtaer Quality Standards. Office of Water Resources, Water Pollution Control Division, 55 p.

Mauersberger, P., 1983
General Principles in Deterministic Water Quality Modeling, in Mathematical Modeling of Water Quality: Streams, Lakes and Reservoirs, G.T. Orlob, ed., Wiley-Interscience, pp. 42-115.

Montgomery, D.C. and E.A. Peck, 1982
Introduction to Linear Regression Analysis, Wiley-Interscience, 504 p.

Neter, J., W. Wasserman and M.H. Kutner, 1985
Applied Linear Statistical Models, Richard D. Irwin, Inc., Homewood, IL, 1127 p.

Organization for Economic Co-operation and Development, 1982
Eutrophication of Waters: Monitoring, Assessment and Control, OECD, Paris, France.

Orlob, G.T., 1983
Future Directions, in Mathematical Modeling of Water Quality: Streams, Lakes and Reservoirs, G.T. Orlob, ed., Wiley-Interscience, pp. 503-509.

Parker, R.A., 1977
Capabilities and Limitations of a Nutrient-Plankton Model., in Modeling the Eutrophication Process, Middlebrooks, Falkenborg and Maloney, eds., Ann Arbor Science, pp. 121-130.

Porcella, D.B., S.A. Peterson, and D.P. Larsen, 1982
Closure comments "Index to Evaluate Lake Restoration". Journal Environmental Engineering Division, ASCE, v.108, EE5, p 1082-1083.

Ram, N.M. and P.E. Austin, 1983
Predicting Algal Stimulatory Properties of Wastewater, Journal of Environmental Engineering, v. 109, n.5, pp. 1099-1110.

Rittmann, B.E. and W.E. Langeland, 1985
Simultaneous Denitrification with nitrification in single-channel oxidation ditches. Journal Water Pollution Control Federation, v.57, n.4, pp. 300-308.

Ryding, S.O., 1981
Optimization of Monitoring Programmes by Means of General Correlations Between Standard Water Quality Variables. Verh. Internat. Verein. Limnol., v.21, pp. 791-798.

Sanders, T.G. and R.C. Ward, 1978
Relating Stream Standards to Regulatory Water Quality Monitoring Practices. Proc. American Water Resources Association Symposium on the Establishment of Water Quality Monitoring Programs, June, 1978, pp 339-348.

Schaeffer, D.J, K.G. Janardan, H.W. Kerster and M.S. Shekar, 1980
Graphical Effluent Quality Control for Compliance Monitoring: What is a Violation? Environmental Management, v.4, n.3, pp 241-245.

Schwartzkopf, S.H. and G.L. Hergenrader, 1978
A Comparative Analysis of the Relatiosnhip Between Phytoplankton Standing Crops and Environmental Parameters in Four Eutrophic Prairie Reservoirs. Hydrobiologia, v.59, n.3, pp 261-273.

Shelef, G. and R. Halperin, 1970
Waterwater Nutrients and Algal Growth Potential in Developments in Water Quality Research, H.I. Shuval ed., Ann Arbor Science, pp 211-228.

Smith, V.H., 1982
The Nitrogen and Phosphorus Dependence of Algal Biomass in Lakes: An Empirical and Theoretical Analysis. Limnology and Oceanography, v. 26, n. 7, pp 1101 - 1112.

Steele, J.H., 1974
The Structure of Marine Ecosystems, Harvard University Press, 128 p.

Tarzwell, C.M., 1983
Water Quality Criteria for Aquatic Life with Special Reference to Dissolved Oxygen and Temperature, Proc. Seminar on Development and Assessment of Environmental Standards, Amer Acad. Envir. Engr., Annapolis, MD, Feb., 1983, pp 39-46.

Taylor, W.D., L.R. Williams, S.C. Hern, and V.W. Lambou, 1979
Phytoplankton Water Quality Relationships in U.S. Lakes, Part VII: Comparison of Some New and Old Indices and Measurements of Trophic State., US EPA, EPA-600/3-79-079, Las Vegas, NV, 51 p.

Thomann, R.V., 1977
Comparison of Lake Phytoplankton Models and Loading Plots, Limnology and Oceanography, v. 22, n. 2, pp 370-373.

U.S. Environmental Protection Agency, 1985
1984 Needs Survey Report to Congress, U.S. Government Printing Office, Washington, D.C., 055-000-00245-2.

Walker, W.W., 1985
Statistical Basis for Mean Chlorophyll a Criteria, in Lake and Reservoir Management: Practical Applications, North American Lakes Management Society, p 57-62.

Ward, R.C. and J.C. Loftis, 1983
Incorporating the Stochastic Nature of Water Quality into Management. Journal Water Pollution Control Federation, v.55,4:408-414.

Whitehead, P.G. and R.J. Williams, 1984
Modelling Nitrate and Algal Behaviour in the Rivers Thames. Water Science Technology, v.16, pp. 621-633.

APPENDIX A

LOUISIANA DEPARTMENT OF ENVIRONMENTAL QUALITY
INTENSIVE SURVEY DATA LISTING

This appendix contains a listing of LA DEQ data that was used in the nutrient criteria model development. Only those records that included corrected chlorophyll a in excess of 10.0 ug/l are included in this listing.

The following abbreviations are used:

BOD20S	20 day BOD suppressed for nitrogenous demand (mg/l)
BOD20	20 day BOD (mg/l)
CHLA	Uncorrected chlorophyll a (ug/l)
C_CHLA	Chlorophyll a corrected for pheophytin (ug/l)
PHEO_A	Pheophytin a (ug/l)
TKN	Total Kjeldahl nitrogen (mg/l)
TP	Total phosphorus (mg/l)
DO	Dissolved oxygen (mg/l)
TEMP	Temperature in degrees C
COND	Conductivity (umhos)
FLOW	Flow in cubic feet per second
DEPTH	Depth of sample (Ft.)

A period in place of any numerical value indicates missing data.

OBS	SEGMENT	SAMPLE	DATE	DEPTH	BOD20	TKN	TP	C_CHLA
1	0203	D1	5/27/80	2.4	45.03	10.70	1.90	41.89
2	0203	D2	5/27/80	.	48.05	29.30	6.00	15.71
3	0203	D3	5/27/80	1.8	43.29	15.00	3.10	71.81
4	0203	D4	5/27/80	1.2	35.06	7.90	0.80	110.71
5	0203	D5	5/27/80	2.1	31.15	7.70	0.80	104.72
6	0203	D6	5/27/80	2.2	14.70	2.10	0.41	49.37
7	0203	D7	5/27/80	3.0	17.18	3.70	0.56	61.34
8	0203	D8	5/27/80	2.3	14.68	2.20	0.53	134.60
9	0501	D2	7/09/80	0.3	37.28	14.82	7.80	22.11
10	0501	D4	7/09/80	0.9	33.30	4.95	1.58	36.29
11	0501	D5	7/09/80	1.1	32.58	4.20	2.71	88.45
12	0501	D7	7/09/80	0.5	14.10	1.04	0.83	25.71
13	0501	D8	7/09/80	0.9	17.20	2.04	1.87	66.50
14	0501	D9	7/09/80	0.9	14.20	1.03	0.19	25.50
15	0515	BY-D2	7/09/80	.	28.32	5.50	3.33	10.90
16	0515	BY-D3	7/09/80	.	29.48	5.00	3.39	28.70
17	0515	BY-D4	7/09/80	.	28.96	3.76	3.18	37.80
18	0504	D3	6/24/80	1.5	22.27	2.65	0.36	33.30
19	0504	D4	6/24/80	1.2	19.35	3.13	0.35	25.70
20	0504	D5	6/24/80	0.9	13.55	1.67	0.32	37.40
21	0504	D6	6/24/80	1.5	16.50	2.01	0.32	22.70
22	0504	D7	6/24/80	1.5	14.60	1.92	0.29	34.80
23	0504	D8	6/24/80	1.5	18.95	2.00	0.29	71.40
24	0504	D9	6/24/80	1.5	19.90	1.84	0.22	78.20
25	1009	D5	7/01/80	.	14.63	1.42	0.09	28.70
26	1005	MB3	7/01/80	0.1	14.65	1.63	0.43	37.40
27	1005	MB4	7/01/80	0.1	6.80	3.34	0.74	13.60
28	1005	MB5	7/01/80	0.1	32.11	9.92	3.22	149.70
29	1211	D3	7/29/80	1.0	8.45	1.18	0.25	23.80
30	1211	D4	7/29/80	2.0	9.10	1.16	0.24	30.60
31	1211	D5	7/29/80	1.0	8.60	0.90	0.24	24.70
32	1211	D6	7/29/80	2.4	9.61	1.63	0.22	30.60
33	1211	D7	7/29/80	4.0	6.80	1.63	0.24	20.40
34	1211	D10	7/29/80	2.7	10.50	2.29	0.25	64.60
35	1211	D11	7/29/80	4.0	11.10	2.39	0.22	51.00
36	1211	D12	7/29/80	2.0	4.70	1.38	0.16	14.50
37	1211	D13	7/29/80	2.8	12.75	1.92	0.21	54.40
38	1211	D14	7/29/80	4.0	7.17	1.38	0.16	20.40
39	1211	D15	7/29/80	2.0	9.75	1.61	0.20	49.30
40	1211	D16	7/29/80	2.0	11.80	1.63	0.19	51.00
41	1211	D17	7/29/80	5.0	10.05	1.60	0.16	34.00
42	1211	D18	7/29/80	3.5	12.17	2.02	1.45	39.10
43	1211	D19	7/29/80	2.0	6.70	1.65	0.17	49.30
44	1211	D20	7/29/80	7.0	8.40	1.25	0.16	52.70
45	1211	D21	7/29/80	.	8.60	2.39	0.33	17.00
46	1211	D22	7/29/80	2.2	9.63	1.96	0.27	45.90
47	1211	D23	7/29/80	6.0	8.40	1.99	0.27	59.50
48	1211	D24	7/29/80	5.2	9.25	1.78	0.26	28.90
49	1211	D25	7/29/80	6.0	7.10	1.16	0.18	23.00
50	1211	D26	7/29/80	5.0	7.85	1.48	0.19	34.00

OBS	SEGMENT	SAMPLE	DATE	DEPTH	BOD20	TKN	TP	C_CHLA
51	1003	D1	7/15/80	0.5	18.90	6.31	0.48	178.60
52	1003	D2	7/15/80	0.2	26.78	12.71	4.53	105.80
53	1003	D3	7/15/80	0.3	27.80	11.91	4.97	54.40
54	1003	D4	7/15/80	1.5	9.90	2.62	0.31	45.40
55	1003	D5	7/15/80	0.5	22.26	5.01	0.73	85.10
56	1003	D6	7/15/80	1.5	19.28	2.20	0.46	97.80
57	1016	D2	6/03/80	0.8	5.60	7.32	0.20	11.20
58	0533	CC3	7/21/81	2.0	43.95	10.90	4.96	109.00
59	0533	CC4	7/21/81	2.0	8.70	1.68	0.42	40.90
60	0533	CC5	7/21/81	5.0	11.40	2.03	0.69	36.10
61	0533	CC6	7/21/81	.	4.70	1.10	0.56	17.50
62	0533	CC7	7/21/81	5.0	6.00	1.38	0.32	54.10
63	0533	CC8	7/21/81	5.5	5.80	1.51	0.17	24.10
64	0533	MC1A	7/21/81	0.1	10.25	1.57	0.28	209.80
65	0533	MC2	7/21/81	0.5	34.95	3.62	0.52	150.40
66	0533	MC2A	7/21/81	0.6	25.50	2.73	0.84	112.80
67	0533	MC3	7/21/81	0.5	32.40	3.50	0.95	180.50
68	0533	MC4	7/21/81	0.7	18.05	3.02	0.57	31.00
69	0533	MC5	7/21/81	1.2	10.85	1.27	0.30	50.80
70	0533	TB1	7/21/81	0.2	39.30	8.34	1.20	71.06
71	0533	TB2	7/21/81	0.4	10.45	1.44	0.67	32.15
72	0533	TB4	7/21/81	2.5	13.20	2.59	0.37	12.22
73	0533	TB6	7/21/81	3.1	12.50	1.86	0.45	13.54
74	0533	TB7	7/21/81	0.9	11.55	1.09	0.33	37.60
75	0415	BB2	6/02/81	2.3	11.85	2.12	0.43	127.00
76	0415	BB3	6/02/81	2.9	8.20	3.13	0.52	42.30
77	0415	BB4	6/02/81	3.4	7.60	1.70	0.30	63.50
78	0415	BB5	6/02/81	3.0	3.75	1.29	0.23	25.70
79	0415	BB5-A	6/02/81	3.0	4.05	1.10	0.12	20.40
80	0415	BB6	6/02/81	3.0	3.70	0.67	0.11	13.60
81	0415	W14-1A	6/02/81	0.3	10.60	3.49	1.99	11.30
82	0415	W14-1B	6/02/81	0.3	19.30	5.78	2.68	10.20
83	0415	W14-2	6/02/81	3.0	29.60	10.36	4.72	90.70
84	0415	W14-3	6/02/81	1.0	6.05	1.84	0.95	21.20
85	0415	W14-4	6/02/81	1.4	6.15	1.37	0.76	19.70
86	1023	OR1	5/19/81	0.5	59.70	15.48	4.31	22.70
87	1023	OR2	5/19/81	0.3	37.10	10.16	4.40	28.70
88	1023	OR3	5/19/81	0.6	36.10	5.16	1.92	21.20
89	1023	OR4	5/19/81	0.5	35.80	13.21	5.73	34.00
90	1023	OR5	5/19/81	0.5	38.70	8.41	1.55	32.60
91	0505	D1-AM	7/07/82	7.3	5.40	0.80	0.16	50.80
92	0505	D2-AM	7/07/82	7.3	4.80	1.21	0.22	34.50
93	0505	D3-AM	7/07/82	7.0	5.80	1.14	0.15	27.70
94	0505	D4-AM	7/07/82	7.3	4.60	0.91	0.15	25.60
95	0505	D5-AM	7/07/82	4.6	9.50	1.00	0.23	22.30
96	0505	D6-AM	7/07/82	4.9	4.40	0.83	0.17	32.50
97	0505	D7-AM	7/07/82	4.3	6.20	1.14	0.23	47.40
98	0505	D8-AM	7/07/82	4.8	6.00	1.05	0.21	38.60
99	0505	D9-AM	7/07/82	15.0	5.30	0.93	0.34	40.60
100	0505	D10-AM	7/07/82	13.0	4.40	0.80	0.19	22.30

OBS	SEGMENT	SAMPLE	DATE	DEPTH	BOD20	TKN	TP	C_CHLA
101	0505	D11-AM	7/07/82	13.0	5.3	0.88	0.17	14.4
102	0505	D12-AM	7/07/82	13.0	4.7	0.84	0.19	38.5
103	0505	D13-AM	7/07/82	12.0	4.1	0.73	0.20	20.3
104	0505	D14-AM	7/07/82	12.0	2.4	0.78	0.19	11.5
105	0505	D15-AM	7/07/82	7.0	2.3	0.83	0.21	15.0
106	0505	D16-AM	7/07/82	7.0	2.9	0.68	0.17	11.5
107	0505	D17-AM	7/07/82	7.0	3.2	0.86	0.24	19.0
108	0505	D24-AM	7/07/82	3.0	4.2	1.07	0.19	18.3
109	0505	D25-AM	7/07/82	1.2	3.5	1.08	0.19	13.2
110	0505	D30-AM	7/07/82	3.5	3.4	1.65	0.30	11.6
111	0505	D31-AM	7/07/82	4.5	4.1	0.50	0.14	17.5
112	0505	D32-AM	7/07/82	5.7	4.4	0.90	0.15	27.1
113	0517	VR21-AM	8/03/82	1.0	35.4	4.29	0.89	53.4
114	0517	VR27-AM	8/03/82	3.0	13.3	1.49	0.69	39.1
115	0517	VR34-AM	8/03/82	3.1	9.1	1.55	0.55	10.2
116	0517	VR38-AM	8/03/82	5.1	7.6	1.28	0.53	10.2
117	0517	VR43-AM	8/03/82	3.0	7.7	1.81	0.85	28.4
118	0517	VR44-AM	8/03/82	4.0	7.7	1.66	0.37	19.6
119	0517	VR45-AM	8/03/82	4.0	5.2	1.36	0.27	11.7
120	0517	VR48-AM	8/03/82	3.0	8.2	1.38	0.28	21.5
121	0801	Q11D-AM	5/18/82	.	31.6	7.28	2.56	25.6
122	0801	Q17 -AM	5/18/82	10.0	3.6	0.96	0.05	16.9
123	0815	TB2	4/27/82	0.5	115.5	15.50	4.51	30.1
124	0815	TB3	4/27/82	.	66.7	6.15	1.55	235.0
125	0815	TB4	4/27/82	.	66.1	6.53	4.25	240.6
126	0815	TB4A	4/27/82	0.7	62.3	7.46	2.50	57.2
127	0815	TB5	4/27/82	.	58.3	8.00	2.76	48.1
128	0404	PAR1	4/20/82	5.5	5.9	0.96	0.15	18.1
129	0404	PAR2	4/20/82	7.0	5.4	1.14	0.23	30.1
130	0404	NR1	4/20/82	1.9	9.3	1.52	0.92	16.5
131	0404	NR2	4/20/82	3.3	11.8	1.45	0.85	49.6
132	0404	NR3	4/20/82	3.3	9.3	1.20	0.60	26.3
133	0404	NR4	4/20/82	3.3	7.7	1.13	0.49	35.5
134	0404	SVC1	4/20/82	2.3	8.3	1.28	0.49	21.1
135	0404	BYF1	4/20/82	0.8	46.2	5.03	1.74	11.3
136	0404	BYF2	4/20/82	1.0	519.0	12.60	4.44	39.3
137	0404	BYF3	4/20/82	1.5	279.0	3.69	2.71	16.5
138	0404	BYF4	4/20/82	2.0	83.4	2.17	1.71	39.1
139	0404	BYF5	4/20/82	2.4	13.4	1.40	0.99	43.6
140	0411	ABR3	6/22/82	4.5	7.0	1.26	0.37	28.4
141	0411	TCH7	6/22/82	7.5	5.7	0.52	0.16	15.6
142	0411	TCH8	6/22/82	6.3	4.3	0.45	0.13	10.8
143	0411	BFR6	6/22/82	4.5	7.3	0.76	0.15	15.6
144	0411	BFR7	6/22/82	4.5	3.4	0.45	0.09	10.2
145	1016	BV1	5/25/82	1.0	6.3	0.70	0.13	10.2
146	1016	BV2	5/25/82	.	19.2	2.48	0.12	60.2
147	1011	HT4	6/08/82	.	.	.	.	15.6
148	1011	CV1	5/04/82	.	30.5	2.84	0.54	33.7
149	1011	CV2	5/04/82	.	9.4	2.26	6.40	27.7
150	1109	AC13-AM	7/20/82	.	34.2	5.44	2.64	111.7

OBS	SEGMENT	SAMPLE	DATE	DEPTH	BOD20	TKN	TP	C_CHLA
151	1109	AC14-AM	7/20/82	.	10.9	1.67	1.37	48.9
152	0418	BV1	6/21/83	1.5	9.9	1.72	0.55	46.0
153	0418	BV5	6/21/83	1.5	5.4	1.13	0.22	17.2
154	0418	RV6	6/21/83	5.0	7.2	0.88	0.11	15.2
155	0418	BV7	6/21/83	1.8	5.0	1.03	0.14	14.6
156	0418	BV8	6/21/83	2.4	4.7	2.01	0.30	17.9
157	0418	BV9B	6/21/83	.	13.1	1.31	0.97	23.9
158	0418	BV10B	6/21/83	.	13.3	1.00	0.51	11.9
159	0418	BV11B	6/21/83	.	16.2	0.13	0.55	13.3
160	0418	BV12B	6/21/83	.	25.4	6.30	1.75	103.0
161	0418	BV22	6/21/83	14.0	3.8	0.91	0.21	16.9
162	0418	BV23	6/21/83	3.5	5.9	1.26	0.26	19.2
163	0404	BYF5	7/06/83	2.6	18.8	1.73	0.67	11.3
164	0404	NR1	7/06/83	2.1	21.5	2.10	0.83	15.9
165	0404	NR2	7/06/83	3.1	17.6	1.89	0.73	12.1
166	0607	CC4	8/16/83	2.3	13.5	1.03	0.37	49.7
167	0607	CC5	8/16/83	4.0	8.7	1.24	0.45	22.5
168	0607	CC6	8/16/83	4.9	5.5	0.89	0.34	21.2
169	0607	TB7	8/16/83	1.0	7.8	0.93	0.23	34.5
170	0402	AR1	RR/30/83	6.7	5.4	0.74	0.19	33.1
171	0402	AR2	8/30/83	4.1	5.1	0.85	0.19	29.2
172	0402	AR3	8/30/83	7.0	7.5	0.79	0.19	41.1
173	0402	BD1	8/30/83	1.5	7.5	0.76	0.31	13.6
174	0402	BD2	8/30/83	1.5	11.9	1.18	0.34	35.8
175	0402	BF1	8/30/83	.	40.4	13.30	3.33	31.1
176	0402	BF4	8/30/83	1.0	14.8	1.68	1.10	58.0
177	0402	BM1	8/30/83	1.1	10.3	1.46	0.44	39.1
178	0402	BM2	8/30/83	2.2	11.0	1.51	0.45	36.4
179	0402	BM3	8/30/83	2.3	10.7	1.51	0.48	39.8
180	0402	BM4	8/30/83	3.0	10.2	1.84	0.50	35.8
181	0402	BM5	8/30/83	3.7	10.2	1.71	0.58	69.6
182	0402	BM6	8/30/83	3.3	11.1	1.47	0.56	59.6
183	0402	DC1	8/30/83	0.2	32.8	2.34	1.42	99.4
184	0402	DC2	8/30/83	0.4	12.4	1.06	0.50	39.8
185	0402	WC1	8/30/83	1.0	12.5	1.33	0.42	39.8
186	0402	WC2	8/30/83	0.5	11.2	1.21	1.06	14.6
187	0402	WC3	8/30/83	1.2	15.4	2.02	0.98	31.8
188	0402	WC4	8/30/83	.	15.3	1.26	0.71	109.3
189	0402	WC5	8/30/83	2.3	63.6	5.22	1.91	55.7
190	0409	LPNE14	9/07/83	2.2	7.6	0.57	0.05	19.9
191	0409	LPNE15	9/07/83	2.0	4.0	0.95	0.06	19.2
192	0409	LPNE17A	9/07/83	2.7	4.0	0.71	0.05	11.9
193	0409	SLT1	9/07/83	9.2	5.7	0.89	0.06	23.2
194	0409	SLT2	9/07/83	6.1	6.9	0.67	0.06	27.2
195	0409	W1401	9/07/83	1.7	27.4	3.20	0.78	14.9
196	0409	W1402	9/07/83	1.9	20.4	2.67	0.70	10.4
197	0409	W1403	9/07/83	1.6	17.2	2.08	0.56	10.5
198	0409	W1404	9/07/83	1.6	13.8	1.82	0.40	16.6
199	0409	W1405	9/07/83	2.3	5.4	1.04	0.09	23.9
200	0408	ABR02	7/26/83	1.0	7.0	1.00	0.31	24.5

OBS	SEGMENT	SAMPLE	DATE	DEPTH	BOD20	TKN	TP	C_CHLA
201	0408	ABR2A	7/26/83	2.7	5.4	0.67	0.10	11.3
202	0408	ABR3	7/26/83	4.0	5.0	0.52	0.08	19.2
203	0408	ABR4	7/26/83	4.3	6.1	0.39	0.07	16.9
204	0408	BFR6	7/26/83	3.4	5.8	0.32	0.05	24.0
205	0408	BZ01	7/26/83	1.6	9.6	1.07	0.47	11.9
206	0408	BZ02	7/26/83	12.0	5.1	0.77	0.15	30.5
207	0408	TCH7	7/26/83	7.9	6.8	0.75	0.17	31.5
208	0408	TCH8	7/26/83	6.2	4.0	0.37	0.10	13.3
209	0408	TCH9	7/26/83	12.5	5.0	0.43	0.10	24.0
210	0408	TCH9A	7/26/83	2.3	4.9	0.49	0.08	18.2
211	0408	TCH9B	7/26/83	3.5	6.8	0.52	0.10	17.6
212	0408	TCH10	7/26/83	9.4	4.7	0.36	0.10	18.6
213	0408	TCH10A	7/26/83	2.9	8.1	0.80	0.82	33.1
214	0408	TCH11	7/26/83	7.3	3.6	0.39	0.12	10.6
215	0408	TCH12	7/26/83	9.4	3.3	0.52	0.13	15.9
216	0408	TCH13	7/26/83	3.5	6.1	0.92	0.11	43.1
217	0207	JP-PS2	9/20/83	1.0	15.7	2.10	0.35	25.7
218	0207	JP-PS3	9/20/83	2.1	17.3	2.50	0.23	49.7
219	0207	JP-PS4	9/20/83	2.0	24.1	3.40	0.53	66.3
220	0207	JP-PS5	9/20/83	1.0	6.0	0.92	0.23	12.4
221	0207	JP-PS6	9/20/83	2.7	27.1	5.10	1.25	82.8
222	0207	JP-PS7	9/20/83	1.0	10.6	1.21	0.17	68.3
223	0207	JP-PS8	9/20/83	0.9	14.4	2.09	0.60	22.4
224	0207	JP-PS9	9/20/83	2.4	14.4	1.71	0.57	17.8
225	0207	JP-PS10	9/20/83	0.9	32.8	4.05	0.23	95.2
226	0207	JP-PS11	9/20/83	0.8	20.7	1.46	0.37	42.2
227	0207	JP-PS14	9/20/83	3.0	25.2	4.54	0.74	10.8
228	0207	JP1	9/20/83	2.5	20.6	2.90	1.15	16.6
229	0207	JP3	9/20/83	2.1	22.6	4.30	0.75	27.1
230	0207	JP4	9/20/83	2.3	22.0	3.70	0.90	34.8
231	0207	JP5	9/20/83	2.2	10.6	2.09	0.24	64.2
232	0207	JP9	9/20/83	2.2	16.9	2.20	0.58	38.1
233	0207	JP10	9/20/83	2.0	106.5	10.20	3.24	13.3
234	0207	JP11	9/20/83	1.5	17.3	2.02	0.30	68.3
235	0207	JP11A	9/20/83	2.4	12.9	1.76	0.35	46.4
236	0207	JP14	9/20/83	2.1	24.0	2.08	0.51	34.8
237	0207	JP15	9/20/83	0.3	5.1	1.07	0.24	12.4
238	0207	JP16	9/20/83	4.0	5.4	1.26	0.21	10.8
239	0207	JP19	9/20/83	6.8	8.7	1.02	0.09	18.6
240	0207	JP20	9/20/83	5.1	7.2	1.25	0.16	14.5
241	0207	JP24A	9/20/83	3.6	5.4	1.10	0.31	11.6
242	0207	JP25	9/20/83	2.0	6.5	1.29	0.33	14.9
243	0207	JP27A	9/20/83	5.9	5.5	1.16	0.30	10.8
244	0207	JP28	9/20/83	4.2	5.5	0.86	0.19	11.6
245	0207	JP28A	9/20/83	4.4	8.3	1.15	0.30	10.8
246	0207	JP28B	9/20/83	4.9	7.1	0.90	0.17	20.7
247	0207	JP29	9/20/83	3.9	10.1	1.36	0.40	16.2
248	0207	JP30	9/20/83	3.7	11.6	0.94	0.46	24.4
249	1005	MN1	8/16/84	0.2	10.9	1.58	0.34	10.6
250	1005	MN2	8/16/84	0.5	36.2	3.54	0.98	15.2

OBS	SEGMENT	SAMPLE	DATE	DEPTH	BOD20	TKN	TP	C_CHLA
251	1005	MN3	8/16/84	0.2	114.5	12.00	3.40	22.5
252	1005	MN5	8/16/84	0.7	20.4	2.70	1.30	34.5
253	1005	MN6	8/16/84	0.3	16.8	2.04	1.10	28.7
254	1005	MN7	8/16/84	0.4	13.0	1.92	0.96	69.6
255	1005	MN8	8/16/84	.	39.9	11.20	2.60	27.2
256	1005	MN9	8/16/84	0.3	54.9	9.90	2.20	20.5
257	1005	MN10	8/16/84	.	29.9	8.80	2.40	30.5
258	1005	MN11	8/16/84	.	30.7	7.40	2.30	51.4
259	1005	MN12	8/16/84	1.9	30.9	5.00	0.95	23.9
260	1005	MN13	8/16/84	4.6	14.3	1.79	0.14	33.1
261	1005	MN14	8/16/84	3.7	18.1	2.60	0.32	51.4
262	1005	MN15	8/16/84	3.3	14.4	1.79	0.23	43.1
263	1005	MN16	8/16/84	4.1	16.2	1.66	0.15	82.8

OBS	BOD20S	CHLA	PHEO_A	DO	TEMP	COND	FLOW
1	20.35	47.2	11.44	2.1	28.3	1.0	.
2	42.72	16.8	2.36	.	.	.	.
3	35.73	68.8	6.43	4.1	28.0	1180.0	.
4	16.26	115.2	9.72	3.2	28.0	1400.0	.
5	16.07	115.2	22.60	4.2	29.0	1.1	0.0
6	8.50	57.6	17.73	5.0	31.3	0.3	.
7	8.00	68.8	16.08	3.1	29.4	0.6	.
8	9.72	137.6	6.43	6.1	29.8	0.4	0.3
9	36.02	28.8	14.11	0.0	26.5	800.0	.
10	11.50	49.6	28.10	1.7	26.0	750.0	.
11	10.90	122.4	71.58	0.8	26.0	700.0	.
12	8.03	32.8	14.94	5.5	29.0	700.0	.
13	10.94	88.0	45.20	5.0	28.0	470.0	.
14	8.00	31.5	12.59	5.0	29.0	500.0	.
15	9.80	13.0	5.70	1.9	28.0	700.0	.
16	7.80	36.0	15.30	2.7	28.0	710.0	.
17	8.30	43.0	10.90	2.7	29.0	750.0	.
18	13.00	43.2	20.90	2.2	30.0	375.0	.
19	10.80	32.0	13.20	2.6	32.0	300.0	36.4
20	7.95	46.8	19.70	2.8	31.0	165.0	27.9
21	12.35	30.0	15.40	3.2	30.0	145.0	29.0
22	8.40	46.4	24.50	2.5	31.0	125.0	27.9
23	12.55	82.8	23.80	2.2	32.0	120.0	23.2
24	13.55	95.4	36.10	4.5	33.5	130.0	0.0
25	10.80	34.4	11.90	7.3	33.0	.	1.1
26	8.80	50.6	27.80	6.6	31.0	245.0	1.4
27	4.80	19.8	13.10	9.0	33.0	650.0	1.2
28	31.63	172.8	48.50	2.2	33.0	800.0	2.0
29	4.50	31.5	16.20	2.5	26.0	360.0	.
30	5.90	38.7	17.00	5.4	26.5	420.0	.
31	4.75	29.7	10.60	5.5	27.0	410.0	.
32	4.80	37.8	15.10	3.7	27.0	3000.0	.
33	6.15	25.2	10.10	5.6	27.0	600.0	.
34	9.15	77.4	26.80	6.2	30.0	6385.0	.
35	10.25	61.2	21.40	8.4	31.1	7669.0	.
36	3.45	17.6	6.50	3.9	32.0	474.0	.
37	9.55	65.7	23.70	7.9	31.4	10000.0	.
38	4.90	26.1	12.00	7.4	31.3	20730.0	.
39	8.30	59.4	21.20	7.6	30.2	4312.0	0.4
40	10.85	60.3	19.50	7.4	29.6	7421.0	.
41	7.15	42.3	17.40	7.7	30.4	8191.0	0.3
42	10.00	45.9	14.20	8.1	31.5	12750.0	.
43	5.30	55.8	13.50	3.4	29.5	11350.0	.
44	6.85	58.5	12.00	9.2	30.9	17000.0	.
45	5.10	23.0	12.60	2.2	29.7	2341.0	.
46	7.00	55.8	20.80	2.5	29.3	3518.0	.
47	8.15	68.4	18.60	6.9	28.0	6000.0	0.8
48	5.80	36.0	14.90	3.8	31.2	2101.0	.
49	4.30	28.8	12.30	3.7	31.0	674.0	.
50	6.05	39.6	11.70	3.8	31.3	2821.0	.

OBS	BOD20S	CHLA	PHEO_A	DO	TEMP	COND	FLOW
51	19.20	216.0	78.60	4.5	31.0	190	.
52	18.75	128.0	46.60	4.7	35.0	1420	.
53	16.08	77.4	48.40	1.7	31.0	1700	.
54	12.15	66.0	43.50	.	34.0	215	.
55	16.78	106.2	44.50	7.1	35.0	550	.
56	12.50	112.5	30.80	2.7	34.0	120	.
57	2.75	14.8	7.70	4.0	25.0	.	1.10
58	28.50	.	71.00	5.6	29.5	780	0.00
59	4.75	.	18.10	2.0	32.5	513	0.00
60	4.80	.	24.30	2.6	32.8	542	0.00
61	2.90	.	15.50	4.4	33.5	843	0.00
62	4.35	.	17.90	5.9	33.9	237	.
63	3.90	.	18.80	4.5	33.0	3714	0.00
64	6.60	.	83.40	3.0	29.0	.	.
65	20.20	.	75.90	6.4	31.5	.	.
66	24.00	.	105.80	7.2	33.5	.	.
67	22.30	.	171.00	0.3	29.5	.	.
68	11.35	.	32.60	0.0	30.5	.	.
69	7.40	.	34.10	2.8	32.5	.	.
70	24.25	.	75.53	20.0	38.0	610	0.10
71	6.45	.	31.50	4.6	32.5	320	0.03
72	6.05	.	23.14	1.2	32.7	281	.
73	7.20	.	21.18	1.3	32.5	303	.
74	7.00	.	35.27	2.1	33.0	222	.
75	14.25	150.4	49.11	5.7	28.7	4001	.
76	14.80	49.6	15.20	1.9	29.3	5250	.
77	11.40	72.0	17.90	2.5	30.8	5538	.
78	5.50	32.8	14.90	5.2	29.3	7250	.
79	4.60	26.1	12.00	6.8	29.9	9040	.
80	4.25	17.6	8.40	8.7	30.8	10520	.
81	22.40	18.4	14.90	4.3	34.0	420	0.00
82	38.95	25.2	31.70	1.5	33.0	440	0.00
83	46.40	123.2	68.50	0.9	26.0	1220	0.00
84	11.40	37.6	34.70	3.4	31.2	219	4.00
85	9.25	29.6	21.00	4.0	30.3	871	0.40
86	48.00	32.8	21.40	0.7	24.8	8079	5.50
87	22.00	38.0	19.50	5.1	25.0	6730	4.50
88	12.00	28.8	16.10	3.1	25.2	4311	6.90
89	11.00	48.0	29.50	4.6	25.3	7036	.
90	12.00	42.4	20.70	2.9	25.6	6960	.
91	1.90	.	22.50	2.5	27.5	170	.
92	2.50	.	20.30	6.2	28.0	170	.
93	3.30	.	21.70	5.0	28.0	110	.
94	2.20	.	24.20	7.2	28.0	170	.
95	4.40	.	16.20	3.2	28.0	430	.
96	2.70	.	23.80	6.6	29.0	350	.
97	3.30	.	33.60	2.6	29.5	311	.
98	3.00	.	29.30	6.1	29.5	301	.
99	3.20	.	25.00	4.4	28.7	229	.
100	2.70	.	17.00	3.2	29.5	173	.

OBS	BOD20S	CHLA	PHEO_A	DO	TEMP	COND	FLOW
101	3.6	.	8.9	3.7	29.5	172	.
102	2.9	.	27.9	4.5	29.2	183	.
103	2.6	.	12.9	4.2	29.5	184	.
104	1.2	.	10.9	2.9	26.6	264	.
105	1.8	.	15.1	2.9	29.1	274	.
106	1.6	.	17.8	3.4	30.0	273	.
107	2.8	.	18.1	4.3	31.1	269	.
108	2.7	.	14.2	4.8	30.2	257	.
109	2.2	.	10.3	4.9	29.8	280	.
110	2.3	.	10.1	5.6	30.9	1114	.
111	4.1	.	8.6	4.9	30.5	41500	.
112	4.3	.	6.5	4.7	30.4	43390	.
113	13.5	.	24.6	4.1	28.0	325	.
114	5.6	.	20.1	5.0	28.4	237	.
115	4.2	.	12.0	1.3	30.0	375	.
116	3.8	.	13.0	1.4	28.9	297	.
117	4.5	.	21.0	2.6	30.1	1702	.
118	4.8	.	19.0	2.4	29.8	1170	.
119	3.3	.	13.6	3.1	29.7	1989	.
120	4.8	.	15.3	4.0	29.0	1604	.
121	16.6	.	31.0	0.7	.	.	.
122	2.3	.	7.8	4.3	27.8	183	.
123	76.2	.	14.5	7.0	24.5	1000	.
124	46.5	.	150.8	14.8	21.0	540	.
125	50.5	.	222.3	18.2	21.0	910	.
126	29.6	.	49.2	7.9	24.0	920	.
127	27.5	.	78.8	5.5	21.5	900	.
128	4.1	.	11.1	5.9	24.4	185	.
129	4.1	.	14.5	5.5	24.3	250	.
130	5.4	.	17.8	2.3	23.5	240	.
131	6.4	.	32.7	4.0	24.4	268	.
132	6.4	.	16.5	3.3	23.9	256	.
133	5.2	.	10.8	3.6	24.2	294	.
134	4.8	.	13.2	2.4	22.9	195	.
135	28.5	.	10.2	0.0	24.5	440	.
136	480.0	.	12.6	0.0	25.0	600	.
137	250.5	.	28.0	0.1	24.5	405	.
138	49.5	.	27.8	2.9	25.0	420	.
139	6.7	.	37.0	4.1	23.6	320	.
140	3.6	.	17.9	3.7	27.8	102	.
141	3.3	.	11.4	4.7	27.8	51	.
142	2.9	.	10.0	5.1	28.7	82	.
143	4.7	.	8.4	5.4	27.9	77	.
144	3.0	.	10.7	5.6	28.0	84	.
145	3.1	.	9.7	4.4	23.0	240	8.1
146	16.2	.	39.3	2.1	25.5	250	0.0
147	.	.	16.6	.	.	.	0.0
148	11.7	.	23.9	2.0	19.5	680	0.1
149	7.4	.	5.2	7.8	24.0	760	0.6
150	11.4	.	23.4	0.5	26.5	310	3.0

OBS	BOD20S	CHLA	PHEO_A	DO	TEMP	COND	FLOW
151	6.6	.	18.00	3.2	26.5	300	4.8
152	7.3	.	35.00	4.6	27.0	2270	.
153	3.8	.	12.70	2.9	26.3	1130	.
154	3.5	.	12.40	8.4	26.8	450	.
155	3.8	.	13.80	8.2	27.7	445	.
156	3.7	.	16.80	5.9	26.6	530	.
157	7.5	.	20.30	2.7	27.0	620	.
158	6.2	.	25.10	2.9	27.3	626	.
159	7.4	.	20.70	5.2	26.9	1726	.
160	15.5	.	76.50	5.0	26.9	1606	.
161	3.1	.	11.10	7.3	27.1	470	.
162	4.5	.	14.70	7.0	26.5	580	.
163	4.5	.	9.20	0.9	28.3	241	.
164	4.8	.	10.10	0.7	28.8	212	.
165	5.0	.	8.40	0.5	28.2	236	.
166	8.9	.	41.00	5.8	30.7	318	.
167	6.0	.	20.10	2.5	25.6	316	.
168	3.5	.	18.20	2.1	30.0	371	.
169	4.8	.	20.70	6.4	31.3	196	.
170	4.1	.	18.90	7.1	32.6	76	.
171	3.8	.	21.30	4.8	31.6	152	.
172	5.4	.	26.70	6.6	32.2	181	.
173	5.1	.	5.70	8.4	29.7	546	.
174	7.4	.	6.80	7.5	32.9	533	.
175	21.2	.	17.70	7.6	34.1	1270	.
176	9.8	.	48.50	2.1	30.0	500	.
177	6.9	.	28.70	0.2	30.1	390	.
178	7.0	.	21.90	0.0	30.2	.	.
179	5.8	.	28.10	1.1	29.0	422	.
180	7.4	.	30.50	0.8	29.1	431	.
181	5.3	.	29.00	3.4	30.1	478	.
182	7.5	.	31.00	1.2	30.1	494	.
183	19.1	.	54.40	14.5	34.7	516	.
184	7.5	.	21.70	5.2	31.8	524	.
185	6.7	.	29.60	10.7	34.3	278	.
186	6.8	.	11.40	12.8	33.5	175	.
187	7.8	.	18.70	6.3	30.6	482	.
188	15.0	.	48.40	3.2	29.3	341	.
189	25.2	.	43.70	1.7	29.0	392	.
190	5.4	.	6.14	6.6	27.6	7859	.
191	3.4	.	6.80	7.0	27.7	7944	.
192	2.4	.	6.20	6.3	27.5	8693	.
193	5.2	.	8.40	6.9	27.6	7254	.
194	5.3	.	7.50	6.9	27.6	7258	.
195	16.3	.	9.40	3.1	26.2	140	.
196	10.7	.	9.60	1.4	26.4	125	.
197	8.6	.	11.20	0.1	25.4	989	.
198	6.9	.	12.30	2.0	26.4	4097	.
199	3.6	.	8.50	6.6	27.8	7001	.
200	7.0	.	18.10	0.2	26.4	110	.

OBS	BOD20S	CHLA	PHEO_A	DO	TEMP	COND	FLOW
201	3.5	.	11.6	2.2	30.1	70	.
202	4.4	.	17.1	8.5	33.0	59	.
203	5.4	.	11.5	8.8	33.5	58	.
204	4.5	.	11.5	8.7	33.0	57	.
205	6.7	.	14.9	2.8	30.6	272	.
206	5.2	.	21.6	4.3	31.8	177	.
207	4.0	.	21.8	4.1	31.9	59	.
208	2.9	.	11.6	7.7	31.7	60	.
209	3.4	.	18.4	8.9	33.6	70	.
210	4.7	.	16.5	8.3	33.2	60	.
211	5.4	.	13.2	8.4	33.7	70	.
212	3.1	.	16.9	8.5	34.2	70	.
213	6.2	.	23.6	8.7	33.3	90	.
214	2.8	.	7.5	6.6	31.6	80	.
215	2.3	.	14.1	5.1	31.6	150	.
216	5.1	.	20.0	7.3	33.0	440	.
217	10.3	.	12.8	3.9	29.1	89	.
218	10.9	.	31.1	4.8	27.0	.	.
219	10.9	.	59.4	.	.	.	.
220	4.3	.	11.2	.	.	.	.
221	15.0	.	51.2	7.4	30.4	300	.
222	7.8	.	27.8	9.6	30.2	.	.
223	7.8	.	21.0	3.5	29.4	.	.
224	8.9	.	15.2	6.2	29.5	.	.
225	15.1	.	47.7	4.3	28.9	.	.
226	15.3	.	42.5	9.6	31.3	.	.
227	11.0	.	13.4	2.7	28.9	1293	.
228	8.8	.	11.5	3.0	30.6	860	.
229	7.9	.	21.6	3.5	31.0	1150	.
230	8.0	.	32.2	3.0	30.2	1170	.
231	7.0	.	41.8	7.0	30.3	670	.
232	9.3	.	40.8	.	.	.	.
233	38.6	.	8.4	.	.	.	.
234	12.2	.	30.2	.	.	.	.
235	9.5	.	37.4	.	.	.	.
236	13.5	.	40.1	.	.	.	.
237	3.1	.	13.2	4.9	29.2	694	.
238	4.8	.	15.8	4.8	29.5	888	.
239	3.2	.	13.4	6.9	29.1	976	.
240	3.6	.	14.1	5.6	29.4	944	.
241	3.6	.	15.0	4.2	28.5	617	.
242	5.0	.	16.6	4.4	29.6	630	.
243	2.8	.	14.9	3.5	28.8	683	.
244	3.8	.	9.1	6.1	29.7	682	.
245	5.0	.	13.9	2.8	29.8	930	.
246	4.6	.	10.8	8.2	30.0	647	.
247	5.5	.	14.9	4.6	30.2	718	.
248	6.9	.	12.0	8.5	30.7	640	.
249	10.1	.	7.1	7.5	31.0	87	1.1
250	13.3	.	12.0	2.0	29.5	198	0.7

OBS	BOD20S	CHLA	PHEO_A	DO	TEMP	COND	FLOW
251	66.9	.	32.7	1.7	27.2	344	3.3
252	9.0	.	31.8	6.6	27.6	156	3.2
253	5.8	.	20.4	6.7	32.4	140	2.5
254	10.3	.	29.0	8.8	29.5	50	2.2
255	28.8	.	16.2	2.0	29.1	266	6.1
256	25.8	.	13.0	0.8	29.8	264	6.1
257	24.3	.	20.0	0.6	30.1	250	6.0
258	19.5	.	29.5	2.1	30.1	233	8.5
259	14.8	.	44.0	3.1	28.8	175	.
260	9.0	.	15.8	8.2	29.0	189	14.3
261	9.8	.	35.4	8.2	28.5	173	54.2
262	8.5	.	33.8	8.7	28.5	168	.
263	10.8	.	43.3	9.6	29.7	165	.

APPENDIX B

STORET DATA LISTING

This appendix contains a listing of STORET data that was used in the nutrient criteria model development. Only those records that included corrected chlorophyll *a* in excess of 10.0 ug/l are included in this listing. Each record has a unique observation number that may be used to reference the various parameter listings.

The following abbreviations are used:

DATE	Date of sample (Year Month Day)
BOD5	5 day BOD (mg/l)
BOD20	20 day BOD (mg/l)
CHLA	Chlorophyll *a* (ug/l)
U_CHLA	Uncorrected chlorophyll *a* (ug/l)
C_CHLA_F	Corrected fluorimetric Chlorophyll *a* (ug/l)
C_CHLA_S	Corrected spectrophotometric Chlorophyll *a* (ug/l)
TKN	Total Kjeldahl nitrogen (mg/l)
DKN	Dissolved Kjeldahl nitrogen (mg/l)
TOKN	Total organic Kjeldahl nitrogen (mg/l)
ORG_N	Organic nitrogen (mg/l)
TNO2NO3	Total nitrites & nitrates (mg/l)
DNO2NO3	Dissolved nitrites & nitrates (mg/l)
TNH3NH4	Total ammonia (mg/l)
DNH3NH4	Dissolved ammonia (mg/l)
TP	Total phosphorus (mg/l)
PO4	Ortho-phosphorus (mg/l)
T_PO4	Total ortho-phosphorus (mg/l)
D_PO4	Dissolved ortho-phosphorus (mg/l)
DO_PROBE	Dissolved oxygen by electronic probe (mg/l)
DO	Dissolved oxygen (mg/l)
TEMP	Temperature in degrees C

A period in place of any numerical value indicates missing data.

The ST_CODE parameter designates the state where the data was collected. The following table presents the state codes for the states represented in the data.

State	Code Number
Alabama	01
Arkansas	05
California	06
Delaware	10
Florida	12
Georgia	13
Idaho	16
Illinois	17
Indiana	18
Iowa	19
Kansas	20
Kentucky	21
Maine	23
Massachusetts	25
Michigan	26
Minnesota	27
Missouri	29
Nebraska	31
Nevada	32
New Jersey	34
New York	36
North Carolina	37
North Dakota	38
Ohio	39
Oklahoma	40
Oregon	41
Pennsylvania	42
South Carolina	45
South Dakota	46
Tennessee	47
Texas	48
Vermont	50
Virginia	51
Washington	53
West Virginia	54
Wisconsin	55

OBS	STATION	DATE	ST_CODE	BOD20	TKN	TP	C_CHLA_S	C_CHLA_F
1	JACKSON4	730918	51	14.00	0.86	0.208	10.2	.
2	MNBE-00-BB15E67	810513	27	5.70	1.79	0.277	39.3	.
3	MNMN-25---05E60	810511	27	6.00	1.90	0.382	29.9	.
4	MNMN-39-BB15E55	810511	27	5.60	1.92	0.342	37.4	.
5	MNMN-70-BB15E55	810512	27	7.20	1.90	0.342	57.7	.
6	MNMN-91-BB15E71	810513	27	8.60	1.92	0.306	42.7	.
7	MN100	810512	27	6.80	2.07	0.320	51.3	.
8	MN101	810511	27	5.80	1.80	0.350	43.8	.
9	MN102	810614	27	16.00	6.53	3.059	60.9	.
10	MN107	810519	27	13.00	1.64	0.167	37.9	.
11	MN108	810519	27	8.30	1.30	0.104	22.1	.
12	MN111	810518	27	13.00	1.44	0.173	47.1	.
13	MN112	810514	27	14.00	1.52	0.227	35.2	.
14	MN115	810513	27	13.00	1.58	0.247	63.6	.
15	MN118	810512	27	7.40	2.00	0.346	50.2	.
16	MN119	810612	27	12.00	2.74	2.339	22.0	.
17	MN119	810613	27	7.50	2.79	3.079	44.2	.
18	MN119	810614	27	13.00	9.30	3.789	54.5	.
19	MN121	810511	27	4.90	1.69	0.269	10.9	.
20	MN121	810614	27	9.10	2.98	0.911	35.2	.
21	MN122	810614	27	10.00	3.84	0.968	25.6	.
22	M04W24	820929	39	4.40	0.70	0.740	.	91.6
23	M05P12	820930	39	3.90	0.50	.	.	114.5
24	M05W01	820930	39	4.30	0.60	0.590	.	72.2
25	M05W02	820930	39	3.90	0.90	0.600	.	129.0
26	N-S002S02	790727	36	8.00	3.82	.	18.1	.
27	N-S002S02	790822	36	8.00	1.92	.	52.8	.
28	N-S002S04	790724	36	4.00	5.89	.	28.2	.
29	N-S002S07	790724	36	6.00	0.93	.	25.5	.
30	N-S002S07	790822	36	7.00	1.93	.	38.8	.
31	N-S002S10	790724	36	3.00	0.85	.	29.5	.
32	N-S002S17	790723	36	6.00	1.16	.	17.6	.
33	T01A56	830815	39	3.40	0.30	0.100	.	16.0
34	T01P01	820825	39	4.30	1.94	.	.	18.0
35	T01W44	820803	39	11.89	2.10	.	.	27.3
36	T01W93	820825	39	4.70	1.28	.	.	27.4
37	T01W93	820827	39	10.19	1.00	1.429	.	36.5
38	T01W95	820825	39	3.50	1.56	.	.	15.4
39	U05W02	830823	39	6.40	1.20	0.420	.	13.8
40	U05W06	830824	39	44.00	3.60	1.750	.	16.4
41	U05W09	830824	39	116.00	11.00	3.250	.	62.9
42	U05W11	830824	39	3.80	0.30	.	.	16.0
43	U05W12	830824	39	23.00	7.70	.	.	34.0
44	U05W13	830822	39	60.00	6.80	3.139	.	26.9
45	V04P02	830809	39	4.20	0.80	0.050	.	21.6
46	WAPORA 10	830830	.	5.30	1.64	1.299	39.8	.
47	WAPORA 12	830830	.	7.10	1.91	0.330	21.6	.
48	WAPORA 4	830831	.	3.00	1.12	0.150	11.3	.
49	WAPORA 5	830831	.	5.80	1.64	0.950	18.0	.
50	WAPORA 7	830830	.	4.90	1.50	0.050	45.4	.

OBS	STATION	DATE	ST_CODE	BOD20	TKN	TP	C_CHLA_S	C_CHLA_F
51	006599	830621	29	3.80	0.47	0.081	12.0	.
52	006599	830622	29	3.30	0.41	0.083	15.8	.
53	006599	830623	29	2.70	0.38	0.058	20.0	.
54	006602	830622	29	3.10	0.67	0.080	13.4	.
55	1C	760714	.	1.60	0.46	0.130	21.0	.
56	1C	760723	.	2.80	0.36	0.080	12.0	.
57	1L	750801	10	0.60	0.60	0.130	16.0	.
58	10C	760714	.	4.40	0.84	0.200	27.0	.
59	10C	760723	.	7.00	0.70	0.160	19.5	.
60	10L	760712	42	7.10	1.39	0.120	24.0	.
61	10L	760714	42	4.40	0.84	0.200	16.5	.
62	10L	760721	42	3.00	0.87	0.150	25.5	.
63	10L	760723	42	2.40	0.40	0.130	19.5	.
64	10R	750804	42	10.23	0.55	0.411	20.5	.
65	10R	750808	42	6.00	1.00	0.213	31.0	.
66	10R	760712	42	6.20	0.75	0.140	16.5	.
67	10R	760714	42	6.00	0.50	0.160	13.5	.
68	10R	760716	42	5.10	2.50	0.190	16.5	.
69	10R	760719	42	6.20	0.65	0.150	28.5	.
70	10R	760721	42	6.40	0.75	0.140	30.0	.
71	10R	760723	42	6.40	0.55	0.170	15.0	.
72	11C	750807	.	11.39	1.35	0.226	51.0	.
73	11C	750814	.	6.00	0.85	0.124	12.5	.
74	11L	750807	42	12.05	1.25	0.201	40.5	.
75	11R	750804	42	3.90	0.85	0.524	31.5	.
76	11R	750807	42	7.68	1.40	0.165	26.5	.
77	11R	750808	42	6.24	1.05	0.288	24.0	.
78	12C	750807	.	8.94	1.20	0.186	20.5	.
79	12C	750814	.	8.82	1.05	0.143	15.5	.
80	12C	760714	.	4.40	1.12	0.200	24.0	.
81	12C	760723	.	6.80	1.24	0.240	28.5	.
82	12L	750807	42	10.51	1.30	0.243	25.0	.
83	12L	750814	42	12.05	1.10	0.131	18.5	.
84	12R	750804	42	9.36	0.90	0.350	25.5	.
85	12R	750807	42	8.55	1.30	0.173	19.5	.
86	12R	750808	42	9.30	1.20	0.156	21.0	.
87	12R	750814	42	5.94	0.75	0.120	13.5	.
88	13C	750807	.	8.64	1.35	0.188	24.0	.
89	13C	750814	.	8.70	0.90	0.144	18.5	.
90	13L	750814	42	10.43	1.25	0.193	13.0	.
91	13R	750804	42	9.66	1.00	0.489	22.5	.
92	13R	750808	42	9.12	1.25	0.202	10.5	.
93	13R	750814	42	6.48	0.87	0.123	17.5	.
94	14C	750814	.	9.24	0.80	0.152	23.0	.
95	14C	760714	.	5.70	1.07	0.200	16.5	.
96	14C	760723	.	6.50	0.97	0.210	30.0	.
97	14L	750807	42	9.12	1.55	0.187	13.0	.
98	14L	750808	42	6.30	1.60	0.210	25.5	.
99	14L	750814	42	9.96	1.00	0.205	23.0	.
100	14R	750804	42	3.96	1.10	0.471	21.0	.

OBS	STATION	DATE	ST_CODE	BOD20	TKN	TP	C_CHLA_S	C_CHLA_F
101	14R	750807	42	9.84	1.30	0.178	13.5	.
102	14R	750808	42	10.01	1.30	0.218	11.5	.
103	14R	750814	42	9.12	0.90	0.140	26.0	.
104	15C	750807	.	10.19	1.45	0.264	12.5	.
105	15C	750814	.	8.94	1.10	0.178	24.5	.
106	15L	750807	42	11.43	1.50	0.241	12.0	.
107	15L	750814	42	11.93	1.00	0.233	23.5	.
108	15R	750804	42	2.70	1.20	0.457	14.0	.
109	15R	750807	42	9.54	1.50	0.196	11.0	.
110	15R	750808	42	8.70	1.20	0.246	10.5	.
111	15R	750814	42	8.52	1.05	0.164	24.0	.
112	16C	750807	.	9.06	1.15	0.232	10.0	.
113	16C	760714	.	5.00	0.78	0.190	28.5	.
114	16C	760723	.	7.20	1.04	0.220	36.0	.
115	16L	750814	42	9.42	1.10	0.226	23.0	.
116	16L	760712	42	6.80	1.22	0.140	25.5	.
117	16L	760714	42	5.50	1.04	0.180	21.7	.
118	16L	760716	42	6.00	1.40	0.190	24.0	.
119	16L	760721	42	5.00	1.21	0.270	21.8	.
120	16R	750804	42	4.20	1.25	0.405	12.0	.
121	16R	750814	42	9.18	1.25	0.205	26.0	.
122	16R	760712	42	6.30	0.50	0.110	25.5	.
123	16R	760714	42	7.50	0.30	0.210	18.0	.
124	16R	760719	42	6.90	1.00	0.240	13.5	.
125	16R	760721	42	7.20	1.00	0.240	22.5	.
126	16R	760723	42	7.90	0.80	0.270	18.0	.
127	17C	750814	.	7.98	1.15	0.257	23.0	.
128	17L	750814	42	8.16	1.10	0.224	18.5	.
129	17R	750804	42	9.24	1.20	0.520	11.5	.
130	17R	750807	42	7.74	1.30	0.195	10.0	.
131	17R	750814	42	8.22	1.05	0.276	21.5	.
132	18C	750814	.	5.34	0.90	0.200	14.5	.
133	18C	760714	.	5.00	0.52	0.200	81.0	.
134	18L	750814	42	11.63	1.85	0.340	15.0	.
135	18R	750804	42	1.98	1.05	0.419	10.0	.
136	18R	750814	42	5.64	0.75	0.195	16.0	.
137	19R	750804	42	7.92	1.10	0.491	19.0	.
138	2R	750804	10	4.74	0.25	0.332	11.5	.
139	2R	750808	10	5.88	0.35	0.126	12.0	.
140	20C	760714	.	5.30	0.51	0.180	101.5	.
141	20C	760723	.	6.10	0.65	0.140	31.5	.
142	20R	750804	42	5.90	1.00	0.418	11.0	.
143	22C	760714	.	6.00	1.06	0.160	97.5	.
144	22C	760723	.	5.70	0.55	0.110	28.5	.
145	22L	760712	42	7.20	1.00	0.170	67.5	.
146	22L	760714	42	5.90	0.79	0.170	82.5	.
147	22L	760721	42	3.60	0.76	0.100	27.0	.
148	22L	760723	42	3.50	0.15	0.080	27.0	.
149	22R	750804	42	4.38	0.65	0.356	19.5	.
150	22R	760712	42	7.60	0.30	0.110	78.0	.

OBS	STATION	DATE	ST_CODE	BOD20	TKN	TP	C_CHLA_S	C_CHLA_F
151	22R	760714	42	9.80	0.88	0.300	85.5	.
152	22R	760716	42	5.10	0.35	0.120	69.0	.
153	22R	760719	42	5.40	0.40	0.120	21.0	.
154	22R	760721	42	5.20	0.60	0.100	27.0	.
155	22R	760723	42	4.70	0.30	0.110	21.0	.
156	24C	760714	.	6.80	0.64	0.130	48.0	.
157	24C	760723	.	6.40	0.50	0.120	82.5	.
158	26C	760714	.	5.80	0.66	0.100	33.0	.
159	26C	760723	.	6.70	0.64	0.130	54.0	.
160	28C	760714	.	5.80	0.75	0.110	28.5	.
161	3C	760714	25	2.50	0.60	0.160	22.5	.
162	3C	760723	25	2.50	0.37	0.070	10.5	.
163	3R	750808	10	5.34	0.40	0.118	15.0	.
164	30C	760714	.	4.30	0.57	0.110	21.7	.
165	30C	760723	.	7.00	0.89	0.120	11.3	.
166	32C	760714	.	4.20	0.55	0.090	16.5	.
167	32C	760723	.	4.70	0.36	0.070	21.0	.
168	332079	760714	34	6.20	0.54	0.090	28.5	.
169	4R	750808	10	4.62	0.40	0.294	11.0	.
170	5C	760714	25	2.00	0.62	0.160	24.0	.
171	5C	760723	25	2.60	0.39	0.100	13.5	.
172	5L	760712	10	3.50	0.90	0.190	22.5	.
173	5L	760714	10	3.60	0.93	0.280	18.0	.
174	5L	760721	10	2.50	1.14	0.170	19.5	.
175	5R	750804	10	5.58	0.50	0.237	20.0	.
176	5R	750808	10	6.90	0.90	0.391	15.0	.
177	5R	760712	10	5.30	1.10	.	33.0	.
178	5R	760714	10	4.40	1.25	0.160	40.5	.
179	5R	760716	10	3.10	0.90	0.240	34.5	.
180	5R	760719	10	2.90	0.50	0.140	15.0	.
181	5R	760721	10	3.10	1.00	0.110	16.5	.
182	501640	820803	39	9.70	1.10	.	.	30.5
183	501640	820804	39	11.09	1.20	.	.	25.7
184	501940	830815	39	4.20	0.40	0.050	.	15.6
185	6R	750804	10	6.18	0.80	0.336	18.0	.
186	6R	750808	10	5.58	0.25	0.276	16.0	.
187	7C	760714	25	3.30	0.69	0.190	13.5	.
188	7C	760723	25	2.60	1.07	0.140	12.0	.
189	7L	760712	10	3.50	1.25	0.090	12.0	.
190	7L	760714	10	3.00	0.94	0.180	16.5	.
191	7L	760721	10	2.10	0.82	0.160	15.0	.
192	7L	760723	10	2.10	0.10	0.130	12.0	.
193	7R	750804	10	3.66	0.80	0.284	18.5	.
194	7R	750808	10	3.72	0.50	0.197	14.0	.
195	7R	760712	10	4.00	0.38	0.090	10.5	.
196	7R	760714	10	5.50	1.40	0.190	10.5	.
197	7R	760716	10	4.60	0.95	0.190	21.0	.
198	7R	760719	10	4.30	0.55	0.140	16.5	.
199	7R	760721	10	4.10	0.60	0.130	18.0	.
200	7R	760723	10	4.80	0.20	0.140	18.0	.

OBS	STATION	DATE	ST_CODE	BOD20	TKN	TP	C_CHLA_S	C_CHLA_F
201	8R	750804	34	3.66	0.70	0.238	19.0	.
202	8R	750808	34	7.07	0.55	0.311	11.0	.
203	9C	760714	25	3.80	0.86	0.140	13.5	.
204	9C	760723	25	3.20	0.63	0.120	12.0	.
205	9R	750804	42	7.44	0.80	0.322	17.0	.
206	9R	750808	42	7.50	0.65	0.194	18.0	.

OBS	BOD5	ORG_N	DKN	TNO2NO3	DNO2NO3	TNH3NH4	DNH3NH4
1	7.5	0.050	.	.	.	0.810	.
2	2.8	1.639	.	14.000	.	0.150	.
3	2.7	1.729	.	13.000	.	0.170	.
4	2.4	1.779	.	13.000	.	0.140	.
5	3.1	1.709	.	12.000	.	0.190	.
6	3.0	1.719	.	11.000	.	0.200	.
7	2.7	1.909	.	12.000	.	0.160	.
8	2.6	1.719	.	13.000	.	0.080	.
9	6.6	5.909	.	17.000	.	0.620	.
10	5.2	1.439	.	0.040	.	0.200	.
11	3.2	1.159	.	0.040	.	0.140	.
12	5.0	1.289	.	0.010	.	0.150	.
13	5.5	1.299	.	0.020	.	0.220	.
14	4.8	1.399	.	0.030	.	0.180	.
15	3.0	1.809	.	12.000	.	0.190	.
16	2.6	1.809	.	0.030	.	0.930	.
17	6.0	2.049	.	0.810	.	0.740	.
18	5.1	8.789	.	6.599	.	0.510	.
19	2.2	1.449	.	0.730	.	0.240	.
20	4.8	2.689	.	7.500	.	0.290	.
21	3.6	3.500	.	12.000	.	0.340	.
22	1.8	.	.	.	.	0.100	.
23	1.9	.	.	.	.	0.050	.
24	2.0	.	.	.	.	0.050	.
25	1.9	.	.	.	.	0.150	.
26	8.0	.	2.98	.	.	0.410	.
27	4.0	.	1.83	.	.	0.310	.
28	4.0	.	4.38	.	.	5.500	.
29	2.0	.	0.86	.	.	0.500	.
30	3.0	.	1.86	.	.	0.390	.
31	2.0	.	0.11	.	.	0.610	.
32	3.0	.	1.44	.	.	0.920	.
33	1.2	.	.	.	.	0.070	.
34	1.9	.	.	.	.	0.080	.
35	4.0	.	.	.	.	0.460	.
36	2.8	.	.	.	.	0.020	.
37	3.3	.	.	.	.	0.050	.
38	1.7	.	.	.	.	0.030	.
39	2.1	.	.	.	.	0.150	.
40	11.0	.	.	.	.	1.599	.
41	17.0	.	.	.	.	6.199	.
42	1.2	.	.	.	.	0.050	.
43	6.3	.	.	.	.	4.929	.
44	13.0	.	.	.	.	4.059	.
45	1.8	.	.	.	.	0.050	.
46	.	.	.	.	.	0.560	.
47	.	.	.	.	.	0.090	.
48	.	.	.	.	.	0.110	.
49	.	.	.	.	.	0.580	.
50	.	.	.	.	.	0.400	.

OBS	BOD5	ORG_N	DKN	TNO2NO3	DNO2NO3	TNH3NH4	DNH3NH4
51	1.70	.	.	0.07	.	0.090	.
52	1.70	.	.	0.15	.	0.070	.
53	2.20	.	.	0.13	.	0.040	.
54	1.40	.	.	0.10	.	0.110	.
55	.	.	.	.	.	0.060	.
56	1.20	.	.	.	.	0.170	.
57	0.60	.	.	.	.	0.300	.
58	2.20	.	.	.	.	0.340	.
59	2.60	.	.	.	.	0.140	.
60	3.20	.	.	.	.	0.390	.
61	3.10	.	.	.	.	0.240	.
62	1.90	.	.	.	.	0.170	.
63	0.90	.	.	.	.	0.100	.
64	2.58	.	.	.	.	0.120	.
65	1.98	.	.	.	.	0.640	.
66	3.30	.	.	.	.	0.320	.
67	3.50	.	.	.	.	0.380	.
68	3.00	.	.	.	.	0.280	.
69	3.20	.	.	.	.	0.280	.
70	3.40	.	.	.	.	0.180	.
71	3.30	.	.	.	.	0.290	.
72	3.96	.	.	.	.	0.840	.
73	2.76	.	.	.	.	0.420	.
74	4.20	.	.	.	.	0.920	.
75	2.04	.	.	.	.	0.420	.
76	3.30	.	.	.	.	0.780	.
77	2.04	.	.	.	.	0.870	.
78	2.40	0.14	.	.	.	1.059	.
79	3.54	0.50	.	.	.	0.550	.
80	1.20	.	.	.	.	0.510	.
81	4.00	.	.	.	.	0.430	.
82	3.62	.	.	.	.	1.039	.
83	4.44	.	.	.	.	0.700	.
84	2.52	.	.	.	.	0.660	.
85	2.16	.	.	.	.	0.910	.
86	2.04	.	.	.	.	1.059	.
87	2.70	.	.	.	.	0.510	.
88	1.74	.	.	.	.	1.000	.
89	3.30	.	.	.	.	0.610	.
90	3.00	.	.	.	.	1.000	.
91	3.18	.	.	.	.	0.700	.
92	1.98	.	.	.	.	1.119	.
93	2.50	.	.	.	.	0.600	.
94	3.20	.	.	.	.	0.710	.
95	1.60	.	.	.	.	0.510	.
96	3.80	.	.	.	.	0.420	.
97	1.40	.	.	.	.	1.079	.
98	1.60	.	.	.	.	1.250	.
99	3.70	.	.	.	.	1.099	.
100	1.90	.	.	.	.	0.920	.

OBS	BOD5	ORG_N	DKN	TNO2NO3	DNO2NO3	TNH3NH4	DNH3NH4
101	1.80	.	.	.	.	0.980	.
102	1.70	.	.	.	.	1.229	.
103	2.80	.	.	.	.	0.700	.
104	.	.	.	.	.	1.229	.
105	2.50	.	.	.	.	0.860	.
106	2.50	.	.	.	.	1.099	.
107	3.20	.	.	.	.	0.830	.
108	1.30	.	.	.	.	0.940	.
109	2.60	.	.	.	.	1.059	.
110	2.00	.	.	.	.	1.119	.
111	1.90	.	.	.	.	0.790	.
112	2.20	.	.	.	.	0.900	.
113	1.60	.	.	.	.	0.340	.
114	3.00	.	.	.	.	0.490	.
115	1.70	.	.	.	.	1.119	.
116	2.50	.	.	.	.	0.520	.
117	2.70	.	.	.	.	0.240	.
118	1.90	.	.	.	.	0.300	.
119	1.70	.	.	.	.	0.610	.
120	1.70	.	.	.	.	1.069	.
121	1.30	.	.	.	.	0.860	.
122	3.20	.	.	.	.	0.480	.
123	3.50	.	.	.	.	0.470	.
124	2.60	.	.	.	.	0.560	.
125	3.30	.	.	.	.	0.530	.
126	3.00	.	.	.	.	0.550	.
127	1.80	.	.	.	.	0.860	.
128	1.40	.	.	.	.	1.019	.
129	1.80	.	.	.	.	0.970	.
130	2.40	.	.	.	.	0.860	.
131	1.60	.	.	.	.	0.670	.
132	1.20	.	.	.	.	0.540	.
133	2.00	.	.	.	.	0.130	.
134	2.52	.	.	.	.	1.479	.
135	1.00	.	.	.	.	0.840	.
136	1.10	.	.	.	.	0.480	.
137	1.80	.	.	.	.	0.780	.
138	2.10	0.16	.	.	.	0.090	.
139	2.40	0.18	.	.	.	0.170	.
140	1.80	.	.	.	.	0.130	.
141	2.40	.	.	.	.	0.230	.
142	1.80	.	.	.	.	0.580	.
143	2.20	.	.	.	.	0.170	.
144	2.60	.	.	.	.	0.150	.
145	2.60	.	.	.	.	0.300	.
146	3.10	.	.	.	.	0.090	.
147	1.60	.	.	.	.	0.060	.
148	1.20	.	.	.	.	0.050	.
149	1.26	.	.	.	.	0.300	.
150	3.30	.	.	.	.	0.190	.

OBS	BOD5	ORG_N	DKN	TNO2NO3	DNO2NO3	TNH3NH4	DNH3NH4
151	3.90	.	.	.	.	0.13	.
152	2.40	.	.	.	.	0.07	.
153	2.00	.	.	.	.	0.07	.
154	2.40	.	.	.	.	0.03	.
155	2.00	.	.	.	.	0.09	.
156	2.40	.	.	.	.	0.30	.
157	2.40	.	.	.	.	0.13	.
158	1.80	.	.	.	.	0.32	.
159	2.70	.	.	.	.	0.30	.
160	1.80	.	.	.	.	0.33	.
161	0.40	.	.	.	.	0.06	.
162	1.10	.	.	.	.	0.09	.
163	2.00	.	.	.	.	0.16	.
164	1.40	.	.	.	.	0.18	.
165	1.80	.	.	.	.	0.64	.
166	1.80	.	.	.	.	0.08	.
167	1.80	.	.	.	.	0.09	.
168	3.60	.	.	.	.	0.06	.
169	1.50	.	.	.	.	0.13	.
170	0.50	.	.	.	.	0.06	.
171	1.10	.	.	.	.	0.09	.
172	1.60	.	.	.	.	0.20	.
173	2.20	.	.	.	.	0.33	.
174	1.30	.	.	.	.	0.44	.
175	1.74	0.42	.	.	.	0.08	.
176	3.30	0.76	.	.	.	0.14	.
177	2.50	.	.	.	.	0.05	.
178	2.30	.	.	.	.	0.05	.
179	1.50	.	.	.	.	0.04	.
180	1.10	.	.	.	.	0.04	.
181	1.20	.	.	.	.	0.06	.
182	4.40	.	.	.	.	0.20	.
183	6.90	.	.	.	.	0.17	.
184	1.80	.	.	.	.	0.05	.
185	2.20	0.67	.	.	.	0.13	.
186	2.30	0.08	.	.	.	0.17	.
187	1.00	.	.	.	.	0.08	.
188	1.00	.	.	.	.	0.09	.
189	1.90	.	.	.	.	0.15	.
190	2.10	.	.	.	.	0.14	.
191	1.10	.	.	.	.	0.22	.
192	0.90	.	.	.	.	0.10	.
193	1.90	0.71	.	.	.	0.09	.
194	1.70	0.39	.	.	.	0.11	.
195	2.20	.	.	.	.	0.18	.
196	2.90	.	.	.	.	0.09	.
197	2.50	.	.	.	.	0.08	.
198	1.80	.	.	.	.	0.08	.
199	2.10	.	.	.	.	0.06	.
200	2.00	.	.	.	.	0.10	.

OBS	BOD5	ORG_N	DKN	TNO2NO3	DNO2NO3	TNH3NH4	DNH3NH4
201	1.90	0.63	.	.	.	0.07	.
202	2.30	0.37	.	.	.	0.18	.
203	1.20	.	.	.	.	0.30	.
204	1.40	.	.	.	.	0.08	.
205	1.92	0.74	.	.	.	0.06	.
206	1.62	0.43	.	.	.	0.22	.

OBS	PO4	T_PO4	D_PO4	U_CHLA	DO	DO_PROBE	TEMP
1	.	.	.	5.6	6.6	.	27.0
2	.	0.146	.	.	10.2	.	15.0
3	.	0.127	.	.	8.8	.	12.0
4	.	0.126	.	.	9.4	.	14.5
5	.	0.171	.	.	9.7	.	13.0
6	.	0.143	.	.	9.7	.	12.0
7	.	0.144	.	.	9.7	.	14.0
8	.	0.162	.	.	9.1	.	14.0
9	.	0.598	.	.	7.9	.	21.0
10	.	0.032	.	.	10.2	.	22.0
11	.	0.065	.	.	10.2	.	16.0
12	.	0.026	.	.	10.2	.	17.5
13	.	0.027	.	.	11.1	.	18.5
14	.	0.081	.	.	11.5	.	18.5
15	.	0.122	.	.	9.6	.	13.5
16	.	1.689	.	.	5.8	.	21.5
17	.	2.149	.	.	4.6	.	23.5
18	.	0.976	.	.	5.6	.	19.0
19	.	0.239	.	.	10.9	.	15.5
20	.	0.470	.	.	8.2	.	20.0
21	.	0.331	.	.	5.8	.	21.0
22	.	.	.	.	.	9.1	19.3
23	.	.	.	.	.	9.3	19.5
24	.	.	.	.	.	7.9	17.5
25	.	.	.	.	.	8.1	17.5
26	.	.	.	.	.	.	.
27	.	.	.	.	.	.	.
28	.	.	.	.	.	.	.
29	.	.	.	.	.	.	.
30	.	.	.	.	.	.	.
31	.	.	.	.	.	.	.
32	.	.	.	.	.	.	.
33	.	.	.	.	.	5.7	24.0
34	.	.	.	.	.	7.6	21.7
35	.	.	.	.	.	6.4	21.0
36	.	.	.	.	.	11.0	22.0
37	.	.	.	.	.	.	.
38	.	.	.	.	.	6.7	20.3
39	.	.	.	.	.	2.5	21.5
40	.	.	.	.	.	1.3	22.4
41	.	.	.	.	.	4.5	25.8
42	.	.	.	.	.	13.7	27.0
43	.	.	.	.	.	.	.
44	.	.	.	.	.	1.8	24.0
45	.	.	.	.	.	.	.
46	.	1.089	.	.	.	5.2	26.0
47	.	0.170	.	.	.	8.8	33.0
48	.	0.010	.	.	.	6.4	25.2
49	.	0.870	.	.	.	7.4	28.0
50	.	0.010	.	.	.	5.4	26.0

OBS	PO4	T_PO4	D_PO4	U_CHLA	DO	DO_PROBE	TEMP
51	.	.	0.011	.	11.0	.	25.0
52	.	.	0.025	.	12.6	.	26.0
53	.	.	0.009	.	.	.	26.0
54	.	.	0.009	.	11.4	.	26.0
55	.	0.060	.	.	6.1	.	24.0
56	.	0.050	.	.	6.4	.	25.0
57	.	0.110	.	.	4.6	.	27.0
58	.	0.080	.	.	2.4	.	24.0
59	.	0.090	.	.	2.9	.	25.5
60	.	0.110	.	.	2.8	.	26.0
61	.	0.100	.	.	3.2	.	25.0
62	.	0.150	.	.	3.4	.	26.0
63	.	0.150	.	.	3.4	.	25.0
64	.	0.133	.	.	9.7	.	29.0
65	.	0.058	.	.	3.3	.	24.0
66	.	0.080	.	.	2.2	.	.
67	.	0.070	.	.	2.7	.	24.0
68	.	0.100	.	.	1.5	.	25.0
69	.	0.070	.	.	3.8	.	24.5
70	.	0.080	.	.	4.3	.	25.0
71	.	0.120	.	.	3.0	.	25.0
72	.	0.108	.	.	1.3	.	27.0
73	.	0.068	.	.	4.7	.	26.0
74	.	0.111	.	.	1.2	.	27.0
75	.	0.198	.	.	4.6	.	28.5
76	.	0.086	.	.	2.2	.	26.5
77	.	0.078	.	.	3.4	.	25.0
78	.	0.131	.	.	0.8	.	27.0
79	.	0.062	.	.	4.1	.	26.5
80	.	0.090	.	.	2.7	.	24.5
81	.	0.140	.	.	1.6	.	25.0
82	.	0.155	.	.	0.7	.	27.0
83	.	0.062	.	.	3.6	.	26.0
84	.	0.238	.	.	4.5	.	28.5
85	.	0.111	.	.	1.7	.	26.5
86	.	0.081	.	.	2.3	.	25.0
87	.	0.056	.	.	4.8	.	26.5
88	.	0.137	.	.	1.1	.	27.5
89	.	0.050	.	.	4.1	.	26.0
90	.	0.105	.	.	2.2	.	26.5
91	.	0.242	.	.	2.9	.	28.5
92	.	0.093	.	.	1.9	.	24.5
93	.	0.047	.	.	4.1	.	26.5
94	.	0.065	.	.	3.6	.	27.0
95	.	0.100	.	.	2.5	.	24.0
96	.	0.130	.	.	1.2	.	25.0
97	.	0.143	.	.	0.5	.	26.5
98	.	0.160	.	.	1.3	.	26.5
99	.	0.063	.	.	3.1	.	27.0
100	.	0.211	.	.	4.0	.	28.5

OBS	PO4	T_PO4	D_PO4	U_CHLA	DO	DO_PROBE	TEMP
101	.	0.143	.	.	1.4	.	26.5
102	.	0.108	.	.	2.0	.	25.0
103	.	0.045	.	.	3.7	.	26.0
104	.	0.182	.	.	0.5	.	27.0
105	.	0.080	.	.	2.8	.	26.5
106	.	0.150	.	.	0.4	.	27.0
107	.	0.048	.	.	2.1	.	26.5
108	.	0.206	.	.	2.8	.	28.5
109	.	0.157	.	.	1.1	.	26.5
110	.	0.124	.	.	1.3	.	25.0
111	.	0.062	.	.	3.0	.	27.0
112	.	0.163	.	.	1.5	.	27.0
113	.	0.090	.	.	4.7	.	23.5
114	.	0.140	.	.	1.4	.	25.0
115	.	0.106	.	.	1.1	.	27.0
116	.	0.120	.	.	5.1	.	25.0
117	.	0.130	.	.	4.3	.	24.0
118	.	0.160	.	.	2.7	.	24.0
119	.	0.190	.	.	2.8	.	25.0
120	.	0.249	.	.	1.3	.	28.5
121	.	0.082	.	.	3.6	.	26.5
122	.	0.080	.	.	3.8	.	.
123	.	0.080	.	.	3.4	.	24.0
124	.	0.160	.	.	2.0	.	24.0
125	.	0.150	.	.	2.5	.	25.0
126	.	0.180	.	.	1.2	.	24.5
127	.	0.120	.	.	1.6	.	27.0
128	.	0.131	.	.	0.9	.	27.0
129	.	0.237	.	.	1.3	.	27.0
130	.	0.154	.	.	1.7	.	26.0
131	.	0.101	.	.	3.3	.	27.0
132	.	0.125	.	.	2.6	.	27.0
133	.	0.050	.	.	6.2	.	23.5
134	.	0.193	.	.	1.7	.	27.0
135	.	0.384	.	.	1.9	.	27.0
136	.	0.126	.	.	2.9	.	27.0
137	.	0.397	.	.	2.9	.	27.0
138	.	0.210	.	.	5.5	.	28.5
139	.	0.063	.	.	6.0	.	26.0
140	.	0.040	.	.	7.0	.	23.5
141	.	0.090	.	.	4.7	.	25.0
142	.	0.351	.	.	4.9	.	27.0
143	.	0.040	.	.	6.7	.	24.0
144	.	0.060	.	.	7.0	.	24.5
145	.	0.080	.	.	6.3	.	25.5
146	.	0.080	.	.	6.3	.	24.5
147	.	0.070	.	.	8.2	.	25.0
148	.	0.080	.	.	7.6	.	24.5
149	.	.	.	.	4.8	.	28.0
150	.	0.050	.	.	6.9	.	.

OBS	PO4	T_PO4	D_PO4	U_CHLA	DO	DO_PROBE	TEMP
151	.	0.060	.	.	7.1	.	23.5
152	.	0.050	.	.	6.8	.	24.0
153	.	0.070	.	.	6.3	.	24.0
154	.	0.050	.	.	7.7	.	24.5
155	.	0.060	.	.	6.9	.	24.0
156	.	0.060	.	.	6.9	.	24.0
157	.	0.030	.	.	7.4	.	25.0
158	.	0.040	.	.	7.3	.	23.0
159	.	0.040	.	.	6.4	.	25.0
160	.	0.040	.	.	7.4	.	23.0
161	.	0.070	.	.	5.2	.	24.5
162	.	0.050	.	.	6.1	.	25.0
163	.	0.066	.	.	.	.	23.0
164	.	0.040	.	.	9.2	.	23.0
165	.	0.050	.	.	7.3	.	26.0
166	.	0.030	.	.	9.2	.	22.5
167	.	0.030	.	.	8.1	.	25.0
168	.	0.020	.	.	.	.	.
169	.	0.073	.	.	5.5	.	25.0
170	.	0.070	.	.	4.8	.	24.5
171	.	0.060	.	.	6.0	.	25.0
172	.	0.170	.	.	3.6	.	26.0
173	.	0.230	.	.	4.6	.	25.5
174	.	0.060	.	.	6.1	.	25.5
175	.	0.150	.	.	5.4	.	28.5
176	.	0.079	.	.	5.5	.	25.0
177	.	0.060	.	.	3.3	.	.
178	.	0.040	.	.	4.4	.	25.0
179	.	0.050	.	.	4.2	.	25.0
180	.	0.050	.	.	5.6	.	24.5
181	.	0.050	.	.	5.6	.	25.0
182	.	.	.	.	.	7.3	19.0
183	.	.	.	.	.	6.1	21.5
184	.	.	.	.	.	9.2	23.5
185	.	0.145	.	.	6.2	.	28.5
186	.	0.064	.	.	6.3	.	25.5
187	.	0.070	.	.	2.7	.	25.5
188	.	0.700	.	.	5.0	.	25.5
189	.	0.090	.	.	2.4	.	26.0
190	.	0.150	.	.	3.0	.	25.5
191	.	0.100	.	.	5.8	.	25.5
192	.	0.080	.	.	5.0	.	25.0
193	.	0.119	.	.	6.6	.	28.5
194	.	0.054	.	.	7.1	.	25.0
195	.	0.070	.	.	.	.	.
196	.	0.040	.	.	3.6	.	24.5
197	.	0.060	.	.	3.3	.	25.0
198	.	0.030	.	.	3.7	.	24.5
199	.	0.060	.	.	4.0	.	25.0
200	.	0.050	.	.	3.8	.	25.0

OBS	PO4	T_PO4	D_PO4	U_CHLA	DO	DO_PROBE	TEMP
201	.	0.110	.	.	7.3	.	28.5
202	.	0.059	.	.	5.5	.	25.0
203	.	0.080	.	.	3.3	.	25.0
204	.	0.070	.	.	3.6	.	25.5
205	.	0.123	.	.	8.2	.	28.5
206	.	0.060	.	.	6.5	.	25.0

APPENDIX C

COMPUTER PROGRAM LISTINGS AND COMPUTATIONS

This appendix contains a listing of selected computer programs that were used in the statistical analysis and model development described in the body of this dissertation. All of the programs were written for use with the Statistical Analysis System (SAS) as installed on the Louisiana State University IBM 3033 computer.

INFLUENTIAL OBSERVATION ANALYSIS

This program performs two sequential influential observation analyses using TKN as the independent variable. The studentized residual is used as the criteria for outlier identification. A critical value of 2.0 was used as the cutoff point for this statistic.

```
//CEMERIP JOB (1304,59805,1,99),'DEAN MERICAS',NOTIFY=CEMERI,
// MSGCLASS=S
/*JOBPARM SHIFT=D
//A EXEC SAS
//STATES DD DSN=CEMERI.DEQ.INTENSE.DATA,DISP=SHR
GOPTIONS DEVICE=BEN9215 VSIZE=6 HSIZE=9
         COLORS=(BLACK1,BLACK2,BLACK3,BLACK4);
*
*          INPUT THE DATA FROM DISK;
*
DATA STREAM;INFILE STATES;
INPUT SEGMENT $ 1-4 SAMPLE $ 6-12 TIME $ DATE $ DEPTH DO TEMP COND
  BOD20S BOD20 TP TKN CHLA C_CHLA PHEO_A FLOW;
  IF C_CHLA='.' THEN DELETE;
  IF C_CHLA LT 10.0 THEN DELETE;

TITLE DEQ INTENSIVE SURVEY DATA;
TITLE2 CHLA GE 10 UG/L;
*                                               ;
*       DO A REGRESSION WITH INFLUENCE STATS GENERATED;
*       AND DISCARD ANY OBS WITH ABS(STUD. RESID) GT 2.0;
*                                               ;
PROC REG; MODEL BOD20=TKN/ INFLUENCE;
    OUTPUT OUT=FIRST P=MODEL RSTUDENT=RSTUD STUDENT=STUD;
    DATA NEXT; SET FIRST;
    IF ABS(RSTUD) GT 2.0 THEN FLAG='OUTLIER';
*                                               ;
*            SEPARATE THE OUTLIERS              ;
*                                               ;
DATA DISCARDS; SET NEXT;
    IF FLAG NE 'OUTLIER' THEN DELETE;
DATA NEXT1; SET NEXT;
    IF FLAG='OUTLIER' THEN DELETE;
*                                               ;
*      REPEAT THE PROCESS A SECOND TIME;
*      AND FLAG ANY OBS WITH ABS(STUD. RESID) GT 2.0;
*                                               ;
PROC REG DATA=NEXT1; MODEL BOD20=TKN / INFLUENCE;
    OUTPUT OUT=SECOND P=MODEL RSTUDENT=RSTUD STUDENT=STUD;
    DATA NEXT; SET SECOND;
    IF ABS(RSTUD) GT 2.0 THEN FLAG='OUTLIER';
```

```
*                                                  ;
*      SEPARATE THE OUTLIERS AND LIST   ;
*                                                  ;
DATA FINAL; SET NEXT DISCARDS;
    IF FLAG NE 'OUTLIER' THEN DELETE;
PROC PRINT;
TITLE IDENTIFIED OUTLIERS;

DATA REMAIN; SET NEXT;
    IF FLAG ='OUTLIER' THEN DELETE;
*                                                  ;
*       MERGE THE TWO DATA SETS                    ;
*                                                  ;
DATA FULL; SET REMAIN FINAL;
    IF FLAG='OUTLIER' THEN OTKN=TKN; ELSE OTKN='.';
    IF FLAG='OUTLIER' THEN TKN='.';
*                                                  ;
*            PLOT THE DATA POINTS;
*                                                  ;
TITLE ;
FOOTNOTE1 .H=1.5 INTENSIVE SURVEY DATA: CHLA>10.0;
FOOTNOTE2 .H=1.5 OUTLIERS PLOTTED AS SQUARES;
PROC GPLOT; PLOT BOD20*TKN BOD20*OTKN / OVERLAY VZERO HZERO;
  SYMBOL1 V=STAR C=BLACK2;
  SYMBOL2 V=SQUARE C=BLACK2;
LABEL BOD20 = 20 DAY BOD (MG/L)
      TKN=TOTAL KJELDAHL NITROGEN (MG/L);
/*
//
```

PIECEWISE REGRESSION

This program performs a piecewise regression using TKN as the independent variable and 20 day BOD as the dependent variable. The model is specified as having two regions with an unspecified joint. Continuity at the joint is not insured.

```
//CEMERIP JOB (1304,59805,3,99),'DEAN MERICAS',NOTIFY=CEMERI,
// MSGCLASS=S
/*JOBPARM SHIFT=D
//A EXEC SAS,REGION=2048K,TIME=3
//STATES DD DSN=CEMERI.DEQ.INTENSE.DATA,DISP=SHR
*                                                            ;
*       INPUT THE DATA FROM DISK;
*                                                            ;
DATA STREAM;INFILE STATES;
INPUT SEGMENT $ 1-4 SAMPLE $ 6-12 TIME $ DATE $ DEPTH DO TEMP COND
  BOD20S BOD20 TP TKN CHLA C_CHLA PHEO_A FLOW;
  IF C_CHLA='.' THEN DELETE;                 * CHLOROPHYLL CONSTRAINT;
  IF C_CHLA LT 10 THEN DELETE;
*;
*          DELETE EXTREME OBSERVATIONS AND OUTLIERS
*;
  IF (SEGMENT='0203') AND (SAMPLE='D2') THEN DELETE;
      IF TKN GT 29 THEN DELETE;   * INSURANCE;
  IF (SEGMENT='0203') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='0501') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1003') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1003') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='1016') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1023') AND (SAMPLE='OR4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB2') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB3') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4A') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF2') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF3') THEN DELETE;

  IF (SEGMENT='0404') AND (SAMPLE='BYF4') THEN DELETE;
  IF (SEGMENT='0402') AND (SAMPLE='WC5') THEN DELETE;
  IF (SEGMENT='0207') AND (SAMPLE='JP10') THEN DELETE;
  IF (SEGMENT='1005') AND (SAMPLE='MN3') THEN DELETE;

TITLE1 DEQ SURVEY DATA FILTERED FOR C_CHLA < 0.010 MG/L;
TITLE2 OUTLIERS VALUES DELETED;
TITLE3 PIECEWISE LINEAR REGRESSION USING TKN;
```

```
PROC NLIN;
PARMS  B0=0.0                              * <=LOWER REGION INTERCEPT
       B1=5.0 TO 8.0                       * <=LOWER REGION SLOPE
       B2=35.0 TO 55.0 BY 5.0              * <=UPPER REGION INTERCEPT
       B3=-5.0 TO 5.0                      * <=UPPER REGION SLOPE
       CUTOFF=4.0 TO 8.0 BY 0.5;           * <=JOINT;
  IF TKN LT CUTOFF THEN DO;
     MODEL BOD20=B0+B1*TKN;
     END;
  ELSE DO;
     MODEL BOD20=B2+B3*TKN;
     END;
OUTPUT PREDICTED=PBOD20 RESIDUAL=RBOD;
TITLE ;
FOOTNOTE1 .H=1.5 INTENSIVE SURVEY DATA: CHLA>10.0;

PROC GPLOT; PLOT BOD20*TKN PBOD20*TKN / VZERO HZERO;
  SYMBOL1 V=- C=BLACK2;
  SYMBOL2 V=NONE I=SPLINE L=1 C=BLACK2;
LABEL BOD20 = 20 DAY BOD (MG/L)
      TKN=TOTAL KJELDAHL NITROGEN (MG/L);
/*
//
```

WEIGHTED ZERO INTERCEPT REGRESSION

This program performs a weighted regression of 20 day BOD against TKN using the inverse of TKN squared as the variance weight. Figure 7 was generated using this program.

```
//CEMERIR JOB (1304,59805,1,99),'DEAN MERICAS',NOTIFY=CEMERI,
// MSGCLASS=S
/*JOBPARM SHIFT=D
//A EXEC SAS,REGION=2048K,TIME=1
//STATES DD DSN=CEMERI.DEQ.INTENSE.DATA,DISP=SHR
GOPTIONS DEVICE=BEN9215 VSIZE=6 HSIZE=9
         COLORS=(BLACK1,BLACK2,BLACK3,BLACK4);
*;
*         READ THE DATA FROM DISK;
*;
DATA STREAM;INFILE STATES;
INPUT SEGMENT $ 1-4 SAMPLE $ 6-12 TIME $ DATE $ DEPTH DO TEMP COND
  BOD20S BOD20 TP TKN CHLA C_CHLA PHEO_A FLOW;
  IF C_CHLA='.' THEN DELETE;                  * CHLOROPHYLL CONSTRAINT;
  IF C_CHLA LT 10 THEN DELETE;
  IF TKN GT 6.000 THEN DELETE;          * LOWER REGION DEFINED;
  TKNI=1/TKN;                                 * WEIGHT;
  TKNI2=TKNI**2;                             * ANOTHER WEIGHT;
*;
*           DELETE EXTREME OBSERVATIONS AND OUTLIERS
*;
  IF (SEGMENT='0203') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='0203') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='0501') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1003') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1003') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='1016') AND (SAMPLE='D2') THEN DELETE;

  IF (SEGMENT='1023') AND (SAMPLE='OR4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB2') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB3') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4A') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF2') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF3') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF4') THEN DELETE;
  IF (SEGMENT='0402') AND (SAMPLE='WC5') THEN DELETE;
  IF (SEGMENT='0207') AND (SAMPLE='JP10') THEN DELETE;
  IF (SEGMENT='1005') AND (SAMPLE='MN3') THEN DELETE;
  IF (SEGMENT='0418') AND (SAMPLE='BV11B') THEN DELETE;
```

```
TITLE1 DEQ SURVEY DATA FILTERED FOR C_CHLA < 10.00 UG/L;
TITLE2 OUTLIERS VALUES DELETED AND TKN LT 6.0 (N=225);
TITLE3 WEIGHTED REGRESSIONS (W=1/TKN**2);
PROC SORT; BY TKN;
PROC REG DATA=STREAM; MODEL BOD20=TKN / NOINT P CLI ; WEIGHT TKNI2;
            OUTPUT OUT=A
            P=PBOD
            U95=U_PBOD
            L95=L_PBOD;
PROC GPLOT DATA=A;
PLOT BOD20*TKN PBOD*TKN U_PBOD*TKN L_PBOD*TKN
       / OVERLAY VZERO HZERO;
  SYMBOL1 V=- C=BLACK2;
  SYMBOL2 I=SPLINE L=1 C=BLACK3;
  SYMBOL3 I=SPLINE L=3 C=BLACK1;
  SYMBOL4 I=SPLINE L=3 C=BLACK1;
TITLE;
FOOTNOTE .H=2 ZERO INTERCEPT WEIGHTED REGRESSION MODEL (W=1/TKN**2);
FOOTNOTE2 .H=1.5 CHLA GT 10 UG/L AND TKN LT 6.0 (N=225);
/*
//
```

ANALYSIS OF COVARIANCE TO EXAMINE STATE DIFFERENCES

This program performs and analysis of covariance using State as the classification variable and TKN as the covariable. The model is overparametized such that the estimates are of the Louisiana slope and the differences between the other state slopes and Louisiana.

```
//CEMERIC JOB (1304,59805,1,10),'DEAN MERICAS',NOTIFY=CEMERI,
// MSGCLASS=S,CLASS=A
/*JOBPARM SHIFT=D
//STEP1 EXEC SAS
//BULK  DD DSN=CEMERI.STORET.DATA,DISP=OLD
//LADEQ DD DSN=CEMERI.DEQ.INTENSE.DATA,DISP=SHR
*;
*           INPUT LA DEQ DATA FROM DISK;
*;
DATA DEQ;INFILE LADEQ;
INPUT SEGMENT $ 1-4 SAMPLE $ 6-12 TIME $ DATE $ DEPTH DO TEMP COND
  BOD20S BOD20 TP TKN CHLA C_CHLA PHEO_A FLOW;
  IF C_CHLA='.' THEN DELETE;                   * CHLOROPHYLL CONSTRAINT;
  IF C_CHLA LT 10 THEN DELETE;
  IF TKN GT 6.00 THEN DELETE;                  * TKN LIMIT;
  TKNI2=1/TKN**2;                              * WEIGHT;
*;
*           DELETE EXTREME OBSERVATIONS AND OUTLIERS;
*;
  IF (SEGMENT='0203') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='0203') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='0501') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1003') AND (SAMPLE='D2') THEN DELETE;

  IF (SEGMENT='1003') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='1016') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1023') AND (SAMPLE='OR4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB2') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB3') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4A') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF2') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF3') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF4') THEN DELETE;
  IF (SEGMENT='0402') AND (SAMPLE='WC5') THEN DELETE;
  IF (SEGMENT='0207') AND (SAMPLE='JP10') THEN DELETE;
  IF (SEGMENT='1005') AND (SAMPLE='MN3') THEN DELETE;
  IF (SEGMENT='0418') AND (SAMPLE='BV11B') THEN DELETE;
  STATE='ZLA';
  DROP SEGMENT SAMPLE TIME DEPTH DO COND BOD20S CHLA;
```

```
*;
*          INPUT STORET DATA FROM DISK;
*;

DATA STORET;INFILE BULK;
  INPUT
  STATION $ 1-15 @16 DAIT YYMMDD6. HOUR 22-23 MINUTE 24-25 ST_CODE 26-27
  @29 BOD20 7.2 @36 BOD5 7.2 @43 C_CHLA_F 7.1 @50 U_CHLA 7.1
  @57 C_CHLA_S 7.1 @64 CHLA 7.1 @71 DO 7.1 @78 DO_PROBE 7.1
  @85 TN 7.2 @92 ORG_N 7.3 @99 DKN 7.2 @106 TKN 7.2
  @113 TOKN 7.2 @120 TNO2NO3 7.3 @127 DNO2NO3 7.3 @134 DNH3NH4 7.3
  @141 TNH3NH4 7.3 @148 PO4 7.3 @155 TP 7.3 @162 D_PO4 7.3
  @170 T_PO4 5.3 @176 TEMP 4.1;
  IF BOD20<BOD5 THEN DELETE;
  IF BOD20<0.001 THEN DELETE;
  FORMAT DAIT YYMMDD6.;
  MUNTH=MONTH(DAIT);
  IF (MUNTH LT 5) OR (MUNTH GT 9) THEN DELETE;  * Warm season data only;
  IF (C_CHLA_S='.') AND (C_CHLA_F='.') THEN DELETE;
  IF (C_CHLA_S<10.0) AND (C_CHLA_F<10.0) THEN DELETE;
  IF TKN GT 6.0 THEN DELETE;               * TKN LIMIT;
  TKNI2=1/TKN**2;                          * WEIGHT;
*;
*              REMOVE OUTLIERS AND INFLUENTIAL OBSERVATIONS;
*;
  IF (ST_CODE='27') AND (BOD20=16.00) AND (TKN=6.63) THEN DELETE;
  IF (ST_CODE='27') AND (BOD20=13.00) AND (TKN=9.30) THEN DELETE;
  IF (ST_CODE='36') AND (BOD20=4.000) AND (TKN=5.89) THEN DELETE;
  IF (ST_CODE='39') AND (BOD20=44.00) AND (TKN=3.60) THEN DELETE;
  IF (ST_CODE='39') AND (BOD20=116.0) AND (TKN=11.0) THEN DELETE;
  IF (ST_CODE='39') AND (BOD20=23.00) AND (TKN=7.70) THEN DELETE;
  IF (ST_CODE='39') AND (BOD20=60.00) AND (TKN=6.80) THEN DELETE;
  DROP STATION HOUR MINUTE BOD5 U_CHLA CHLA DO DO_PROBE ORG_N DKN TOKN
       TNO2NO3 DNO2NO3 DNH3NH4 PO4 D_PO4 T_PO4;
*;
*        IDENTIFY THE STATES OF INTEREST;
*;
  IF ST_CODE='.' THEN STATE='NO NAME';
  IF ST_CODE=10 THEN STATE='DE';
  IF ST_CODE=27 THEN STATE='MN';
  IF ST_CODE=39 THEN STATE='OH';
  IF ST_CODE=42 THEN STATE='PA';
  IF STATE='.' THEN DELETE;
DATA ALLDATA; SET DEQ STORET;
*         FULLY FILTERED DATA - STATE AS A CATAGORICAL VARIABLE;
PROC GLM; CLASSES STATE;
          MODEL BOD20=TKN STATE*TKN / NOINT SOLUTION E; WEIGHT TKNI2;
TITLE1 DEQ AND STORET DATA SETS;
TITLE2 FILTERED FOR CHLA, OUTLIERS REMOVED, CLASSED BY STATE (N GT 15);
TITLE3 ANALYSIS OF COVARIANCE WITH WEIGHTED VARIANCE;
```

NOMOGRAPH GENERATION

The probability of exceeding any given BOD level at any given TKN concentration is calculated by integrating the predicted BOD distribution between the critical BOD value and positive infinity:

$$\text{Risk of Exceedence} = \int_{BOD_c}^{\infty} (SE_p \sqrt{2\pi})^{-1} \; \mathrm{Exp}[-0.5 \; ((x - BOD_p)/SE_p)^2]$$

where SE_p = Standard error of the predicted observation (mg/l)

BOD_c = Critical BOD level (mg/l)

x = BOD (mg/l)

BOD_p = Mean predicted BOD at the given TKN level (mg/l)

The following program generates the probabilistic criteria model nomograph as presented in Figure 10 of the text by fitting a weighted regression model and outputing the mean predicted BOD and error terms for each observed TKN value. The above integration is then performed for a range of BOD standard values from 5 to 40 mg/l to obtain the predicted risks of exceedence.

```
//CEMERIN JOB (1304,59805,1,95),'DEAN MERICAS',NOTIFY=CEMERI,
// MSGCLASS=S
/*JOBPARM SHIFT=D
//A EXEC SAS
//STATES DD DSN=CEMERI.DEQ.INTENSE.DATA,DISP=SHR
OPTIONS PAGESIZE=60;
GOPTIONS DEVICE=BEN9215 VSIZE=7 HSIZE=9
    COLORS=(BLACK1,BLACK2,BLACK3,BLACK4);
*;
*           INPUT DATA FROM DISK;
*;
DATA STREAM;INFILE STATES;
INPUT SEGMENT $ 1-4 SAMPLE $ 6-12 TIME $ DATE $ DEPTH DO TEMP COND
  BOD20S BOD20 TP TKN CHLA C_CHLA PHEO_A FLOW;
  IF C_CHLA='.' THEN DELETE;                    * CHLOROPHYLL CONSTRAINT;
  IF C_CHLA LT 10 THEN DELETE;
  IF TKN GT 6.0 THEN DELETE;                    * DEFINE LOWER REGION;
  TKNI2=1/TKN**2;                               * VARIANCE WEIGHT;
*;
*           DELETE EXTREME OBSERVATIONS AND OUTLIERS
*;
  IF (SEGMENT='0203') AND (SAMPLE='D2') THEN DELETE;
      IF TKN GT 29 THEN DELETE;    * INSURANCE;
  IF (SEGMENT='0203') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='0501') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1003') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1003') AND (SAMPLE='D3') THEN DELETE;
  IF (SEGMENT='1016') AND (SAMPLE='D2') THEN DELETE;
  IF (SEGMENT='1023') AND (SAMPLE='OR4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB2') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB3') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4') THEN DELETE;
  IF (SEGMENT='0815') AND (SAMPLE='TB4A') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF2') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF3') THEN DELETE;
  IF (SEGMENT='0404') AND (SAMPLE='BYF4') THEN DELETE;
  IF (SEGMENT='0402') AND (SAMPLE='WC5') THEN DELETE;
  IF (SEGMENT='0207') AND (SAMPLE='JP10') THEN DELETE;
  IF (SEGMENT='1005') AND (SAMPLE='MN3') THEN DELETE;
  IF (SEGMENT='0418') AND (SAMPLE='BV11B') THEN DELETE;
```

```
TITLE INTENSIVE SURVEY DATA: CHLA>10.0, TKN LE 6.00;
TITLE2 OUTLIERS ELIMINATED (N=225);
PROC SORT; BY TKN;

*     PERFORM A WEIGHTED REGRESSION AND OUTPUT THE RESULTS;
*;
PROC REG; MODEL BOD20=TKN/P R NOINT; WEIGHT TKNI2;
  OUTPUT OUT=RESULTS P=BOD_HAT R=RESID STDP=PRE_ERR STDR=SQRT_MSE;
DATA NOMOGRAF; SET RESULTS;
*;
*  PREDICTED OBSERVATION ERROR = ERROR IN THE PREDICTED MEAN
*                          + ERROR IN THE OBSERVATIONS ABOUT THE MEAN;
  E_PDCT=SQRT((PRE_ERR**2.0)+(SQRT_MSE**2.0));
*;
*         CALCULATE THE AREA UNDER THE NORMAL DISTRIBUTION THAT;
*         IS ABOVE THE VARIOUS BOD STANDARD VALUES;
*;
  EXED5=1-PROBNORM((5-BOD_HAT)/(E_PDCT));
  EXED10=1-PROBNORM((10-BOD_HAT)/(E_PDCT));
  EXED15=1-PROBNORM((15-BOD_HAT)/(E_PDCT));
  EXED20=1-PROBNORM((20-BOD_HAT)/(E_PDCT));
  EXED25=1-PROBNORM((25-BOD_HAT)/(E_PDCT));
  EXED30=1-PROBNORM((30-BOD_HAT)/(E_PDCT));
  EXED35=1-PROBNORM((35-BOD_HAT)/(E_PDCT));
  EXED40=1-PROBNORM((40-BOD_HAT)/(E_PDCT));
*;
*         PLOT THE RESULTS;
*;
  TITLE1 ;
  TITLE2 ;
  TITLE3 ;
  FOOTNOTE .F=TRIPLEX .H=2 BOD20 LEVELS:.F=
    TRIPLEX  5, 10, 15, 20, 25, 30, 35 & 40 MG/L;
  FOOTNOTE2 .H=1 LA DEQ DATA - WEIGHTED REGRESSION (1/TKN**2);
  PROC GPLOT; PLOT EXED5*TKN EXED10*TKN EXED15*TKN
    EXED20*TKN EXED25*TKN EXED30*TKN EXED35*TKN EXED40*TKN /OVERLAY
    HREF=1 2 3 4 5 6 LH=2 CH=BLACK1
    VREF=.1 .2 .4 .6 .8 1.0 LV=2 CV=BLACK1;
  LABEL EXED5=PROBABILITY OF EXCEEDENCE TKN=MG/L KJELDAHL NITROGEN;
  SYMBOL1 V=NONE L=1 I=SPLINE;
  SYMBOL2 V=NONE L=4 I=SPLINE;
  SYMBOL3 V=NONE L=1 I=SPLINE;
  SYMBOL4 V=NONE L=4 I=SPLINE;
  SYMBOL5 V=NONE L=1 I=SPLINE;
  SYMBOL6 V=NONE L=4 I=SPLINE;
  SYMBOL7 V=NONE L=1 I=SPLINE;
  SYMBOL8 V=NONE L=4 I=SPLINE;
/*
//
```

VITA

Constantine "Dean" Evan Mericas was born on October 14, 1951 in New York City to parents of Greek and Norwegian heritage. After living for periods of time in New York, Venezuela and Pennsylvania, his family settled in New Orleans, Louisiana. He graduated with Honors from De La Salle High School in 1969 and received a B.S. in Biology from the University of New Orleans in 1973. He spent six years with the National Oceanic and Atmospheric Administration's Commissioned Officer Corps, leaving with the rank of Lieutenant in 1979. He was self employed as a hydrographic survey consultant in Saudi Arabia and renovated a 65 year old house in Oakland, California prior to entrance into the LSU graduate program in 1981. He received a Masters of Engineering degree in Environmental Engineering from LSU in December of 1982. Upon completion of his Doctorate degree, he will join Lockheed Engineering and Management Services Company's Environmental Services division in Las Vegas, NV as Scientific Supervisor on their acid rain project.

DOCTORAL EXAMINATION AND DISSERTATION REPORT

Candidate: Constantine E. Mericas

Major Field: Environmental Engineering

Title of Dissertation: A Probabilistic Development of Nutrient Criteria for Louisiana Rivers and Streams.

Approved:

Ronald F. Malone

Major Professor and Chairman

William Dyer

Dean of the Graduate School

EXAMINING COMMITTEE:

Ronald F. Malone

Dr. Ronald F. Malone, Chairman

Joseph N. Suhayda

Dr. Joseph Suhayda

Marty Tittlebaum

Dr. Marty Tittlebaum

Stephen D. Field

Dr. Stephen Field

James P. Geaghan

Dr. James Geaghan

Flora C. Wang

Dr. Flora Wang

William E. Kelso

Dr. William Kelso

Date of Examination:

September 6, 1985